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PRELIMINARY AIR POLLUTION SURVEY OF MERCURY AND ITS COMPOUNDS

A LITERATURE REVIEW

LITTON SYSTEMS, INCORPORATED
BETHESDA, MARYLAND

PREPARED FOR
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
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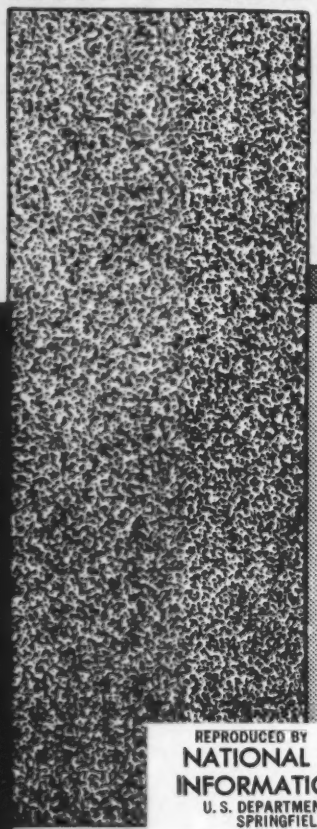

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A LITERATURE REVIEW

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PRELIMINARY
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OF
MERCURY AND ITS COMPOUNDS

A LITERATURE REVIEW

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Environmental Systems Division

Prepared under Contract No. PH 22-68-25

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
National Air Pollution Control Administration
Raleigh, North Carolina
October 1969

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National Air Pollution Control Administration Publication No. APTD 69-40

FOREWORD

As the concern for air quality grows, so does the concern over the less ubiquitous but potentially harmful contaminants that are in our atmosphere. Thirty such pollutants have been identified, and available information has been summarized in a series of reports describing their sources, distribution, effects, and control technology for their abatement.

A total of 27 reports have been prepared covering the 30 pollutants. These reports were developed under contract for the National Air Pollution Control Administration (NAPCA) by Litton Systems, Inc. The complete listing is as follows:

Aeroallergens (pollens)
Aldehydes (includes acrolein and formaldehyde)
Ammonia
Arsenic and Its Compounds
Asbestos
Barium and Its Compounds
Beryllium and Its Compounds
Biological Aerosols (microorganisms)
Boron and Its Compounds
Cadmium and Its Compounds
Chlorine Gas
Chromium and Its Compounds (includes chromic acid)
Ethylene
Hydrochloric Acid
Hydrogen Sulfide
Iron and Its Compounds
Manganese and Its Compounds
Mercury and Its Compounds
Nickel and Its Compounds
Odorous Compounds
Organic Carcinogens
Pesticides
Phosphorus and Its Compounds
Radioactive Substances
Selenium and Its Compounds
Vanadium and Its Compounds
Zinc and Its Compounds

These reports represent current state-of-the-art literature reviews supplemented by discussions with selected knowledgeable individuals both within and outside the Federal Government. They do not however presume to be a synthesis of available information but rather a summary without an attempt to interpret or reconcile conflicting data. The reports are

necessarily limited in their discussion of health effects for some pollutants to descriptions of occupational health exposures and animal laboratory studies since only a few epidemiologic studies were available.

Initially these reports were generally intended as internal documents within NAPCA to provide a basis for sound decision-making on program guidance for future research activities and to allow ranking of future activities relating to the development of criteria and control technology documents. However, it is apparent that these reports may also be of significant value to many others in air pollution control, such as State or local air pollution control officials, as a library of information on which to base informed decisions on pollutants to be controlled in their geographic areas. Additionally these reports may stimulate scientific investigators to pursue research in needed areas. They also provide for the interested citizen readily available information about a given pollutant. Therefore, they are being given wide distribution with the assumption that they will be used with full knowledge of their value and limitations.

This series of reports was compiled and prepared by the Litton personnel listed below:

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The NAPCA project officer for the contract was Ronald C. Campbell, assisted by Dr. Emanuel Landau and Gerald Chapman.

Appreciation is expressed to the many individuals both outside and within NAPCA who provided information and reviewed draft copies of these reports. Appreciation is also expressed to the NAPCA Office of Technical Information and Publications for their support in providing a significant portion of the technical literature.

ABSTRACT

Elemental mercury and most of its derivatives are protoplasmic poisons which can be lethal to man, animals, and plants. Russian experiments with animals indicate continuous exposure to mercury vapor above 0.3 $\mu g/m^3$ of air may present a health hazard. Some organic mercury compounds, particularly the alkyl derivatives, are much more toxic than elemental mercury or the inorganic compounds. Recent air measurements of particulates in New York indicate that the mercury concentration of indoor samples is as high as 40 $\mu g/m^3$, or several times higher than that found safe in animal experiments using mercury vapor. The mild symptoms of mercury intoxication are psychopathological in nature and thus can present serious problems in diagnosing the cause. Animals and plants appear to have a lower threshold to the toxicity of mercury vapors and compounds than humans.

The mining and refining of mercury and the use of mercury in industrial and scientific laboratory applications appear to be significant sources of air pollution. Very little data are available on concentrations of mercury in the atmosphere.

Methods for the control of mercury air pollution are available but may not be adequately employed. No information has been found on the economic costs of mercury air pollution or the costs of its abatement. Several methods are known for the determination of measurement of mercury in the atmosphere.

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LIST OF FIGURES

1. U.S. Consumption and Production of Mercury, 1935-66 . 29
2. Mercury Consumption by Uses, 1947-66 34
3. Saturation Concentration of Mercury in Air Versus Temperature 38

LIST OF TABLES

1. Summary of Mercury Toxicity Data Via Inhalation . . . 72
2. Properties and Uses of Mercury 73
3. Saturation Concentration of Mercury in Air at Various Temperatures 74
4. Mercury Consumed in the U.S. by Uses, 1947-1966 . . . 75
5. Properties and Uses of Some Mercury Compounds 77
6. U.S.A. Production of Mercury by States (1936-56) . . 83
7. Major Mercury Mines in 1963 and Their Locations . . . 84
8. List of Major Mercury-Producing Mines in 1966 85
9. Directory of Selected Producers, Consumers, and Dealers of Mercury 86
10. List of Some Companies Producing Mercury Chemicals (1968) 89
11. Mercury-Containing Pesticides 90

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CONTENTS

FOREWORD

ABSTRACT

1. INTRODUCTION 1

2. EFFECTS 4

2.1 Effects on Humans 4
2.1.1 Absorption, Distribution and Excretion 4
2.1.2 Inhibition of Enzymes 7
2.1.3 Toxicity 8
2.1.3.1 Mercury and the Inorganic Compounds 9
2.1.3.1.1 Acute Toxicity . . . 9
2.1.3.1.2 Chronic Toxicity . . 10
2.1.3.2 Organic Mercury Compounds . . . 12
2.1.3.2.1 Alkyl Mercury Compounds 12
2.1.3.2.2 Other Organic Mercury Compounds. 13
2.2 Effects on Animals 14
2.2.1 Commercial and Domestic Animals 14
2.2.2 Experimental Animals 15
2.3 Effects on Plants 19
2.4 Effects on Materials 23
2.5 Environmental Air Standards 24
2.5.1 Mercury and Its Inorganic Compounds . . 24
2.5.2 Mercury Organic Compounds 26

3. SOURCES

3.1 Natural Occurrence 28
3.2 Production Sources 28
3.3 Product Sources 32
3.4 Environmental Air Concentrations 39

4. ABATEMENT 42

5. ECONOMICS 45

6. METHODS OF ANALYSIS 46

REFERENCES 51

APPENDIX 71

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1. INTRODUCTION

Elemental mercury (Hg), although it is a metal, is unique in that it is a liquid at normal temperatures. This property plus its high specific gravity and electrical conductivity has brought about its widespread use in industry and various types of laboratory equipment and instruments. When mercury is spilled or splashed, either in transference or by breakage of an apparatus, the mercury tends to separate into very tiny droplets that become entrapped in small cracks and crevices, rugs, etc. Moreover, even when an attempt is made to pick up the spilled mercury, some mercury still remains. This exposed mercury, because of its high vapor pressure at room temperature, constantly emits vapors into the environmental air. In addition, any source which heats mercury (or mercury compounds)--such as mining and refining operations, mercury-arc rectifiers, mercury precision casting, etc.,--presents potential air pollutant hazards if not carefully controlled. Therefore, mercury vapor is always present in the atmosphere.

In addition to mercury vapor, mercury compounds may also result in air pollution. These compounds normally exist in the ambient air as aerosols. For the purposes of this report, the compounds will be divided into two main categories: inorganic mercury compounds and organic mercury compounds. The inorganic

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compounds include the ionically bonded mercurous and mercuric salts, such as mercurous chloride and mercuric chloride. The organic compounds include those compounds in which mercury is covalently bonded to a carbon atom, as in the case of dimethyl mercury and phenylmercuric acetate.

The major sources of pollution by mercury compounds are the industrial manufacturers and users of these compounds. Agricultural use of organic mercury compounds as pesticides may also be a source of air pollution. However, there has been a general decrease in the use of mercury-containing pesticides in the past years (see Section 3.3). The fact that presently no mercury residue is allowed in foodstuffs in the United States should cause this declining trend to continue. A list of pesticide formulations containing mercury is given in Table 11 in the Appendix. Further information on mercury pesticides can be found in the review by Smart[184] and references therein.

Elemental mercury and most compounds of mercury are protoplasmic poisons and therefore may be lethal to all forms of living matter. In general, the organic mercury compounds are more toxic than mercury vapor or the inorganic compounds. Even small amounts of mercury vapor or many mercury compounds can produce mercury intoxication when inhaled by man. Acute mercury poisoning, which can be fatal or cause permanent

damage to the nervous system, has resulted from inhalation of from 1,200 to 8,500 $\mu g/m^3$ of mercury.[159] The more common chronic poisoning (mercurialism) which also affects the nervous system is an insidious form in which the patient may exhibit no well-defined symptoms for months or sometimes years after exposure. The symptoms usually associated with mercurialism are erethism (exaggerated emotional response), gingivitis, and muscular tremors. A person suffering from a mild case of mercury poisoning is usually unaware of the cause of the illness because the symptoms are psychopathological in nature. Likewise, these ambiguous symptoms may result in an incorrect diagnosis by a physician. In addition, animals and plants also exhibit a low tolerance to mercury and its compounds.

2. EFFECTS

2.1 Effects on Humans

It has been well documented that inhalation of air contaminated with mercury vapor or certain mercury compounds may result in intoxication or poisoning by the absorption of toxic amounts of mercury via the respiratory tract. Neal et al.[107,108] demonstrated a correlation between the mercury concentration in the atmosphere and the prevalence of chronic mercurialism.

Furthermore, inhaling mercury vapors or mercury compounds may be more detrimental to the body than the other means of entry such as ingestion. For example, there are data which suggest that absorption via the respiratory tract leads to a higher rate of accumulation of mercury in the brain than via the other routes of absorption.[17,30,31] Once mercury passes the blood-brain barrier, it becomes more strongly bound in the brain than in any other organ of the body.[60,144]

2.1.1 Absorption, Distribution and Excretion

Several studies have been conducted to determine the extent to which mercury vapor is absorbed from the human respiratory tract. Gerstner[67] found that inhalation of air containing from 10 to 100 $\mu g/m^3$ of mercury vapor resulted in absorption of 34 to 77 percent of the mercury. However, Gothlin[77] found almost

complete absorption when the concentration of mercury vapor was less than 250 $\mu g/m^3$, and Shepherd *et al.*[151] found no detectable exhaled mercury vapor with a concentration of 60 $\mu g/m^3$ and about 10 $\mu g/m^3$ of exhaled mercury vapor with an initial concentration of 200,000 $\mu g/m^3$. Kudsk[98] found that 67 to 88 percent of the mercury vapor was absorbed in the range of 50 to 350 $\mu g/m^3$. The latter concluded that when the physiological dead space is considered, then for the range of concentrations studied there is also complete absorption of mercury vapor from the alveoli of the lungs in normal individuals. He[99] also noted that ingestion of ethyl alcohol had an inhibitory influence on the absorption of mercury vapor by inhalation.

Browning[34] reported that organic mercury compounds are absorbed to a lesser extent than the inorganic compounds when ingested. Upon passing through the alveolar and capillary walls, elemental mercury and mercurous compounds appear to be readily oxidized to mercuric salts.[34,157] The mercuric salts form soluble compounds with blood, tissue, fluids, and proteins.[157] Another conjunctive route for metallic mercury was suggested by Hughes.[64] The solubility of elemental mercury in lipids allows rapid diffusion through the lipid-containing cell membranes (the alveolar walls) followed by transport by the blood lipids to sensitive tissues, such as the brain. The metallic mercury is

then oxidized to the mercuric ion, which then reacts with the thiol groups of the proteins. In contrast, some of the organic-bound mercury compounds are not readily converted to inorganic mercurial compounds by the blood, but by the kidneys and liver instead.[61,64,65,125] Furthermore, some organic mercury compounds are retained in the blood for longer periods, penetrate blood-cell barriers more easily, and become more firmly bound to tissues than the inorganic mercury compounds.[56,58,163] When ingested, mercury compounds, whether organic or inorganic, become widely distributed in all tissues.[7,17,61,162,163] The highest accumulation occurs normally in the kidneys, with the next highest in the liver; these compounds also accumulate in the brain, spleen, and alimentary tract. The organic compounds appear to concentrate to a greater extent in the brain and liver than the inorganic compounds, however.

Inhaled mercury vapor and mercury compounds are normally excreted as inorganic mercury in the urine and feces, with lesser amounts excreted in the bile, sweat, saliva, and milk.[7,34,157] Mercury can also be transferred to a fetus through the placenta[49] and to the newborn through the mother's milk.[127] For example, Butt and Simonsen[39] reported that in a 7-week-old infant who died with moist gangrene of the extremities, mercury was found in the kidneys and liver. The infant's only known contact with mercury

was through the mother, who was exposed to mercury vapors during pregnancy. Smith et al.[183] recently reported a strong correlation between mercury vapor exposure levels (time-weighted) and the mercury content of the blood and urine of workers in chlorine plants.

Although mercury is excreted from the body as mentioned above, sometimes excretion continues for several months after exposure to mercury.[33,131,159] The rate of excretion depends on individual differences, type and duration of exposure, and the mercury derivative. In general, the excretion rate decreases logarithmically with time after exposure has ceased.

2.1.2 Inhibition of Enzymes

The ultimate effect of mercury and related compounds is the inhibition of enzyme action.[10] It is not clearly understood which enzymes are inhibited, and to what degree, in the production of mercury intoxication symptoms. Nonetheless, it is known that both inorganic and organic mercury compounds exhibit affinity for thiol or mercaptan groups (SH groups) in enzymes, and to a lesser degree the organic ligands of enzyme systems, such as amino, carboxyl, and hydroxyl substituents.[10,44] Passow et al.[135] also found that mercury ions can react with phosphoryl groups in cell membranes. There is some evidence that mercury ions can inhibit certain enzyme systems in vitro, including phenolsulfate conjugation, citrulline, phosphorolysis, oxidative

mitochondrial phosphorylation, serine biosynthesis, and cytochrome C oxidase.[21,147] At low concentrations in the system, the mercury ions become bound primarily to the mercaptan groups, while at higher concentrations other types of substituents become involved.[27]

2.1.3 Toxicity

The major factors that determine the effect of mercury poisoning on humans are (1) amount and rate of absorption, (2) physicochemical properties of the compounds inhaled, and (3) individual susceptibility.[10,76] The first factor is illustrated by the fact that although acute poisoning produces primarily nephrogastrointestinal effects, with more severe exposures, pulmonary changes predominate. On the other hand, chronic poisoning is usually indicated by neurological effects. Several authors have noted a wide range of individual susceptibility. Although these differences are not fully understood, they have been explained in part by the varying capacity of an organ for binding and releasing mercury.[2,112,179] Variations in the toxicity of mercury compounds are indicated by their diverse uses, ranging from diuretics and antiseptics to highly toxic fungicides and herbicides.

Inhalation of mercury vapor or mercury-containing substances can lead to insidious chronic poisoning and even an acute

form of poisoning. Acute poisoning is not as prevalent as the chronic type but can arise from exposure to high concentrations (usually from environments where mercury is near to or in contact with a heated surface), or from exposure to the more toxic compounds, particularly the alkyl-mercury derivatives. In some cases, the patient suffering from chronic poisoning exhibits no well-defined symptoms until years after exposure. The toxicity of elementary mercury and its compounds has been reviewed by Battigelli,[10,11] Brown and Kulkarni,[33] and Stokinger;[159] also a review by an international committee is forthcoming.[142] A summary of the symptoms of acute and chronic mercury poisoning by means of inhalation is given in Table 1 in the Appendix.

2.1.3.1 Mercury and the Inorganic Compounds

2.1.3.1.1 Acute Toxicity

In some instances, inhalation of mercury in concentrations of 1,200 to 8,500 $\mu g/m^3$ results in acute intoxication,[159] affecting primarily the digestive system and kidneys. Acute intoxication is characterized by a metallic taste, nausea, abdominal pain, vomiting, diarrhea, headache, and sometimes albuminuria.[159] After a few days, the salivary glands swell, stomatitis and gingivitis develop, and a dark line of mercuric sulfide forms on the inflamed gums. Furthermore, teeth may loosen and ulcers may appear on the lips and cheeks. Axelsson and Friberg[8] cite as

symptoms gastroenteritis, anuria (with uremia), stomatitis, and ulcerohemorrhagic colitis. Severe exposure to mercury vapor produces tightness and pain in the chest, difficulty in breathing, and coughing.[28] Severe cases of acute poisoning are characterized in later stages by hemolysis, sleeplessness, headache, facial tics, digital tremors, delirium and hallucinations.[51] Death as a result of extreme exhaustion frequently occurs with poisoning of this degree of severity. In milder cases of acute mercury poisoning, some patients recover within 10 to 14 days, but others may develop the chronic symptoms, such as muscular tremors or erethism.

2.1.3.1.2 Chronic Toxicity

The symptoms observed in poisoning by mercury vapor and inorganic mercury compounds are the same. However, the inorganic compounds, which normally occur in air as aerosols, should be less toxic than mercury vapor because of their differences in uptake and deposition.[142]

Chronic poisoning is more common than the acute form and primarily affects the nervous system. The usual symptoms of chronic poisoning are erethism, gingivitis, and muscular tremors.[11,56] Any of these symptoms may be present without the others and in varying degrees, thus frequently complicating the diagnosis. Moreover, the mildest symptoms are psychopathological in nature

and may be exhibited by persons who have had no known exposure to mercury. Thus, as a result of exposure to mercury, a person may develop nervous anxiety, insomnia, or loss of appetite, yet his case may never be diagnosed as mercurialism.

Erethism is characterized by exhibition of undue embarrassment, timidity, depression, discouragement, irritability, resentfulness, or excitability.[11,53,131,159] Other aspects are loss of the abilities to concentrate and remember, fear, and indecision. Thus, erethism consists of exaggerated emotional responses in general. Tremors are the most frequently reported physical symptom. They can vary from a slight movement of the hands, eyelids, or tongue to a disabling, intense trembling which affects the whole body.[11,159] Early stages consist of tremors of the lips and tongue, followed by the fingers and hand.[86] Ataxia follows, first expressed as stammering (dysarthria) and difficulty in swallowing (dysphagia), and later as increasing coordination in arms and legs. Severe cases may intensify to entirely uncoordinated movements, impaired hearing, and inability to communicate by writing or speaking.

Gingivitis leading to recession of gums and loss of teeth has been questioned as a reliable indicator of mercurialism.[11] Nonetheless, gingivitis, which results from poor oral hygiene, is probably aggravated by mercury exposure.

Other symptoms noted include such neurological disturbances as paresthesia, impairment of taste or smell, neuralgia, and dermographism.[159] Stomatitis--sometimes severe--and excessive salivation are also common. Chronic nasal catarrh and epistaxis, as well as renal disease and ocular lesions, are often found.

2.1.3.2 Organic Mercury Compounds

The organic mercury compounds cover a wide range in toxicity, but may generally be divided into two categories on the basis of toxicity: (1) the alkyl mercury compounds, which are stable compounds and appear to act on the nervous system; and (2) the other organic mercury compounds, which are less stable, degrading to inorganic mercury, and are similar in toxicity to inorganic mercuric salts.

2.1.3.2.1 Alkyl Mercury Compounds

The symptoms of acute and chronic poisoning for the alkyl organomercury compounds are similar.[142] Furthermore, the symptoms, even in acute poisoning, may not be noticeable until weeks or months after exposure.

Poisoning due to alkyl mercury compounds is indicated by some major neurological symptoms and leads to permanent damage or death.[175] Cases of severe exposure have produced permanent impairment of the nervous system, such as gross ataxia,

aphasia, sensory loss in the limbs, impaired vision and hearing, personality changes, and loss of intellectual capacity.[11,86,89] In severe cases the symptoms are irreversible. In an example related by Hunter,[88] a 16-year-old boy exposed to methyl mercury compounds for only a few months who had sustained severe damage to his nervous system was still unable to work after 20 years because of persistent ataxia, tremors, and inability to recognize objects by touch.

Inhalation of alkyl mercury derivatives can produce sensations of dryness and irritation in the nasopharynx and mouth and even lead to blistering.[175] In general, alkyl mercury compounds affect predominantly the motor and sensory nerves, while the inorganics are more likely to produce symptoms of excessive salivation, stomatitis, and erethism.[33]

Cases of mental retardation with convulsive cerebral palsy have been reported in infants born to mothers who were exposed to large amounts of methyl mercury during pregnancy.[57,117]

2.1.3.2.2 Other Organic Mercury Compounds

Organic mercury compounds other than the dialkyl derivatives are in general rapidly converted in the body to inorganic mercury compounds.[142] Thus, these organic compounds show toxicities and symptoms similar to those of the inorganic mercury

compounds (see section 2.1.3.1). Information on the toxicity of these compounds is very limited.

Methoxyethyl mercury, a fungicide, has been reported to cause symptoms associated with inorganic mercury compounds, including loss of appetite and weight, diarrhea, and fatigue.[142]

Goldwater et al.[75] reported evidence of kidney damage from heavy exposure to phenylmercuric acetate; however, the damage may have been related to a simultaneous acid burn of the skin.

No conclusive evidence of toxic effects in humans from long-term exposure to phenyl mercury salts has been reported.[142] Massman reported on 26 human subjects with up to 6 years' exposure to phenylmercuric pyrocatechin (240 to 3,200 $\mu g/m^3$) with no clinical evidence of injury. Goldwater et al.[74,103] studied more than 100 workers exposed to phenyl mercury compounds in the air (usually with some inorganic salts also present). Thirty-five of the workers had been exposed to mercury concentrations up to 5,100 $\mu g/m^3$, with the air concentrations generally exceeding 290 $\mu g/m^3$. No cases of poisoning were recorded in either study.

2.2 Effects on Animals

2.2.1 Commercial and Domestic Animals

No qualitative or quantitative data were found concerning mercury poisoning for animals exposed to typical environmental conditions. Farm animals have been poisoned as a result

of eating plants treated with mercury-containing pesticides.[24] An incident of mercury poisoning in cattle stabled overnight with a horse that had been treated with a mercury skin ointment was also described. Heimann[82] reported on an incident described by Henderson and Haggard[84] in which symptoms of mercury poisoning developed in cows and other domestic animals after a fire in a nearby mercury mine.

2.2.2 Experimental Animals

Papers describing the toxic effects of mercury and its compounds on animals are too numerous to be reviewed in detail in this report. However, important papers relating to inhalation of mercury-containing substances and air pollution will be summarized. More detailed summaries can be found in the reviews of Battigelli,[10,11] Brown and Kulkarni,[33] and Stokinger,[159] and in the references mentioned therein.

Kurnosov[100] conducted experiments in which white rats were continuously exposed to a low concentration of mercury vapor for 9.5 months. Rats that inhaled the vapor in the concentration ranges of 20 to 30, 9 to 10, and 2 to 5 $\mu g/m^3$ of air showed an accumulation of mercury in the kidneys, liver, and to a lesser extent in the brain and heart. They also exhibited pathomorphological changes and disturbances of the functional activity of the higher nerve centers. The degree of neurological and

pathomorphological changes appeared to be proportional to the mercury concentration. The author also cited reports which showed that inhalation of 100 to 7,000 $\mu g/m^3$ of mercury resulted in the death of laboratory animals.

Ashe et al.[7] studied the responses of animals exposed to mercury vapor at concentration levels of from 100 to 6,000 $\mu g/m^3$ for as long as 83 weeks. In rabbits exposed to mercury vapors at 6,000 $\mu g/m^3$ for 6 weeks there was severe damage to the kidneys, heart, lungs, and brain. In dogs he found no damage after 83 weeks of exposure to a mercury vapor concentration of 100 $\mu g/m^3$. At a concentration of approximately 860 $\mu g/m^3$, significant damage to the brain and kidneys was noted after 6 weeks, although the damage disappeared when the animal was no longer exposed. The authors pointed out that the animals have a greater susceptibility to renal tissue damage by mercury vapors than do humans, and that this type of data cannot therefore be applied quantitatively to man.

These authors also determined the U/A ratio (amount of mercury in urine to amount being inhaled) at 100 $\mu g/m^3$ of mercury vapor. After several weeks, a steady-state ratio of 0.14 for rabbits and 0.4 for dogs was attained. In contrast, in humans exposed to the same concentration of combined mercury vapor and dusts for months to years, the U/A ratio was 7. Some factors

responsible for the higher U/A ratio in humans than in animals may be a higher rate of pulmonary deposition, absorption, or urinary excretion of mercury. The U/A ratio decreases as the concentration of mercury increases for both humans and animals, although the decrease is greater for humans.

Frazer et al.[58] found that dogs exposed to mercury vapor of 3,000 $\mu g/m^3$ of air or less for 40 days showed no signs of intoxication. However, an increase to 3,000 to 6,000 $\mu g/m^3$ for the same length of time produced effects on the central nervous system and digestive tract. In addition, death resulted after eight days at 6,000 to 20,000 $\mu g/m^3$ or a few hours at 20,000 $\mu g/m^3$.

Gage[64] has shown that rats inhaling 100 $\mu g/m^3$ of mercury vapor for short periods had a rapid turnover of mercury in all tissues except the brain, and that the mercury was eliminated within one week after the exposure was discontinued. However, after prolonged exposure the mercury was converted by the kidneys to a derivative which was excreted very slowly.

Several authors have studied the effects of inorganic and organic derivatives on animals.[18-20,60-62,138,167] These studies are based mainly on injection of the compound rather than inhalation. Clarkson et al.[43] and Berlin[16] consider that the mode of administration is irrelevant, since they believe that

mercury entering the body by inhalation does not behave differently from mercury compounds injected into the system. In general, their results suggest that mercury, in animals as in humans, is widely distributed in the body but mainly concentrated in the kidneys and liver and to a lesser extent in the brain, and that the organic mercury compounds are more toxic to animals than inorganic mercury by a factor of 5 to 20. Moreover, the organic mercurials--especially the alkyl derivatives--appear to concentrate more rapidly in the brain tissues and are also more tightly bound to most tissues.

Beliles et al.[14] exposed pigeons to an average mercury vapor concentration of 80 $\mu g/m^3$ for 6 hours a day for 20 weeks and found no behavioral, histological, or gross signs of mercurialism. However, Armstrong et al.[5] found notable changes in the behavior of pigeons after 14 weeks at 17,000 $\mu g/m^3$.

It was noted in the previous section that humans absorb nearly all of the mercury vapor inhaled in the concentration range of 50 to 350 $\mu g/m^3$. However, in dogs exposed to concentrations of from 3,000 to 26,000 $\mu g/m^3$, the amount of inhaled mercury absorbed varied from 21 to 23 percent. Gage[59] also found that rats absorbed only about 50 percent of the mercury vapor when exposed to 1,000 $\mu g/m^3$. It is not known whether this is due to the difference in the absorption ability of human and

animal lungs, the higher concentration of mercury vapor, or other factors.

In summary, it appears that animals exhibit toxicity symptoms similar to man but are more susceptible to lower concentrations of mercury.

2.3 Effects on Plants

Evidence has been published that clearly demonstrates the phytotoxicity of vapor from metallic mercury and its compounds in a certain variety of roses and other species of plants. Although injury to plants has been noticed only when the plants are located in a confined atmosphere containing a source of mercury, examples are given where the mercury content of the air was less than 10 $\mu g/m^3$ and yet severe damage to roses resulted. Various species and varieties of plants differ widely in their susceptibility to mercury poisoning. The extent of damage to a particular species of plant depends mainly on factors which influence the vaporization of mercury, such as source of mercury, temperature, air-flow rate, and initial concentration. It is generally believed that the phytotoxicity of mercury compounds is primarily due to the mercury vapors arising from thermal decomposition or catalytic reduction of the compound to metallic vapor.[85] Lesions caused by both organic and inorganic mercury compounds are indistinguishable from those caused by metallic mercury.

The damage to certain species of roses from mercury poisoning consists of brown or black discoloration of the leaves, petals, peduncles, and corollas of the young buds. Further exposure results in stronger discoloration, followed by abscission of the leaves and the young buds. Injured plants may recover from the mercury poisoning if removed from the contaminating source. Slightly injured plants produce normal shoots from various parts of the plant in one to two months. However, badly injured roses may not initiate normal growth or flowering for several months, and then only from the lower part of the plant.

Another important aspect of mercury poisoning in plants is their tendency to accumulate large amounts of mercury in leaves and various other parts. One experiment is reported in which approximately 4,000 ppm of mercury was found in tobacco leaves after the soil was moistened with a 1 percent solution of mercuric chloride for one week. Even though the leaves contained a high concentration of mercury, the tobacco plant itself exhibited only slight damage.

Only a few papers exist which describe the effect of mercury on plants. Some early experiments with mercury are reported by Boussingault,[25,26] in which mint, petunias, peach twigs, and bean plants were exposed to metallic mercury vapors. These plants developed dark spots and blackening of the leaves and stems,

with eventual collapse and premature falling of the leaves. During 90-hour experiments, it was noticed that damage increased with the duration of the mercury exposure.

Interest in the phytotoxicity of mercury was stimulated again in 1933 when some Briarcliff roses were accidentally injured in a commercial greenhouse: the mature roses had faded, while the petals on the buds of the younger plants had turned brown. Other species of roses in the same greenhouse did not exhibit any sign of damage. Zimmerman and Crocker[181] experimentally verified the fact that the injury to the roses resulted from an application of mercuric chloride for earthworm control. Further investigation suggested that in the presence of Tankage--a fertilizer having a high organic matter content--mercuric chloride had a much greater effect than the mercury compound alone. Ratsek[140] found in similar experiments with both mercury and mercuric chloride that the leaves of the roses accumulate mercury. He also found that the amount recovered in the leaves was dependent upon the surface area exposed to mercury.

Zimmerman and Crocker[182] further studied the effect of Tankage fertilizer on the apparent increase in phytotoxicity of mercuric chloride. The results of these experiments showed that the injury to roses from mercuric chloride was caused by the metallic mercury vapor produced from the decomposition of the

mercuric chloride, which was found to be catalyzed in the presence of organic matter (such as that used in Tankage). These investigators then conducted additional experiments with mercury using other species of plants. Some of the plants which they found particularly susceptible were the broad bean, butterfly weed, oxalis, and sunflower, as well as nine varieties of roses. Some plants relatively resistant to the vapor were aloe, croton, English ivy, oak, and pachysandra. Peach, privet, tomato, geranium, and Boston fern exhibited intermediate susceptibility.

Zimmerman and Crocker[182] analyzed the leaves of different species after about one week's exposure to mercuric chloride. Some of the results were Briarcliff rose 317, Coolidge rose 808, and Turkish tobacco 2,405 to 3,747 ppm of mercury (by dry weight). It is interesting that the Briarcliff is more susceptible to damage by mercury than the Coolidge rose, and both are more susceptible than the tobacco, which showed only slight damage.

Recent reports indicate that certain plants are injured when exposed to mercury fumes resulting from decomposition of paints containing mercuric fungicides. Butterfield[40] reported two cases of mercury poisoning in Better Times roses caused by emanations from a fungicide paint on the walls of the greenhouse. A greenhouse freshly painted with the same fungicide paint showed only a slight reading on a mercury vapor detector (about 10 $\mu g/m^3$)

after 24 hours. After 20 days in this greenhouse, however, Peter's Briarcliff roses exhibited minor lesions, and after an additional week of exposure severe injury was apparent.

Diamond and Stoddard[53] reported a similar case of damage to roses arising from the use of mercury fungicide paint inside a greenhouse. The paint contained about 0.08 percent mercury by weight in the form of the fungicide di-(phenylmercuric) dodecenyl succinate (DPMDS). Analysis of the air surrounding the injured roses showed no detectable mercury vapors (the lower limit of the detector was 10 $\mu g/m^3$). However, analysis of the roses showed that the petals contained 1.3 ppm of mercury (fresh weight) and the leaves 3.3 ppm. Roses not exposed to mercury contained 0.2 ppm of mercury in the petals and 0.07 in the leaves. When tested, the fungicide DPMDS slowly decomposed at room temperature, releasing mercury vapor into the atmosphere.

Hitchcock and Zimmerman[85] have reviewed in detail the reports of mercury poisoning of plants up to 1957. Thomas[164] also has reviewed air pollutants (including mercury) which are harmful to plants.

2.4 Effects on Materials

No information on damage to materials by mercury was found. However, it may be possible that even at low concentrations, mercury will slowly collect on certain metallic surfaces

and penetrate the material by amalgamation. If the concentration of mercury becomes too high, the strength of the material may be weakened.

2.5 Environmental Air Standards

2.5.1 Mercury and Its Inorganic Compounds

The American Conference of Governmental Industrial Hygienists[165] has adopted the threshold limit value (TLV) of 100 $\mu g/m^3$ for mercury vapor and inorganic compounds of mercury for an 8-hour work day. The TLV[55] is based on studies of human exposure in the felt hat industry by Neal et al.[129] and on unpublished results by Fahy[55] in the electronics and lamp industries. However, there are several examples which suggest that this level should be changed. Goldwater et al.[73] cited the studies of Smith et al.,[155,156] Bidstrup,[22] and Neal et al.[128] on the exposure of workers to a concentration of less than 100 $\mu g/m^3$ of mercury vapor and inorganic compounds which resulted in mercury poisoning in 5 to 12 percent of those exposed. However, a study by Kleinfield et al.[95] on workers exposed to inorganic mercury compounds in the range of 80 to 400 $\mu g/m^3$ (an average exposure of approximately 200 $\mu g/m^3$) for more than two years found that these workers exhibited no evidence of mercury intoxication.

Stokinger[159] in a review on mercury feels that with the current TLV, a relatively small margin of safety for mercury vapor

exists, although with the mercury inorganic salts there is a greater safety factor. Several authors have shown concern that this TLV may be too high, especially in the case of mercury vapor. The ACGIH Threshold Limit Values Committee is considering lowering the TLV for "inorganic" mercury to 50 $\mu g/m^3$ air, on the basis of unpublished studies by the chlorine industry.[48] In 1968 an International Symposium recommended 8-hour Maximum Allowable Concentrations (MAC) of 50 $\mu g/m^3$ for mercury vapor and 100 $\mu g/m^3$ for the inorganic salts.

No studies have been found that suggest or set a 24-hour exposure limit for mercury in the United States. However, in a discussion with B. F. Craft,[48] Dr. H. E. Stokinger suggested that a 24-hour limit for mercury be no higher than 10 $\mu g/m^3$ (based on a limit of 50 $\mu g/m^3$ for 8 hours).

In 1963, a maximum allowable concentration of metallic mercury of 0.3 $\mu g/m^3$ of environmental air for a 24-hour exposure was established in Russia (the U.S.S.R.'s maximum occupational 8-hour exposure limit to inorganic mercury is 10 $\mu g/m^3$). This Russian 24-hour limit was based on animal experiments.[143] Long-term experiments with rats at a level of 2 to 5 $\mu g/m^3$ of mercury vapor in air affected the functional activity of higher nervous centers, caused mercury deposition in the brain and other organs, and produced pathomorphological changes.[100]

2.5.2 Mercury Organic Compounds

Because of the higher toxicity of many of the organic-bound mercury compounds, the ACGIH[165] has established a TLV for organic mercury of 10 $\mu g/m^3$ for an 8-hour exposure, a factor of 10 less than that for inorganic mercury. This TLV is based mainly on the studies of Ahlmark,[1] Lundgren and Swensson,[109] Trakhtenberg,[166] and Dinman et al.[54] The former two studies[1,109] are occupational studies in which alkyl mercury compounds were being used. The data provided in these two studies do not include the atmospheric concentrations of the mercury compounds nor the methods of analysis. Ahlmark[1] concluded that the limit should be 10 $\mu g/m^3$. On the basis of the finding that mice died upon being exposed for 3 to 5 hours at 10,000 to 30,000 $\mu g/m^3$ of organic mercury (ethyl mercuric phosphate and chloride) in air, Trakhtenberg,[166] in 1951, concluded that humans could not tolerate exposures of 0.01 $\mu g/m^3$ on a continuing basis. In the more recent study by Dinman et al.,[54] in 1958, 20 workers were exposed to organic mercury (ethyl mercuric phosphate and chloride adsorbed on inert clay and solvent solutions of ethyl or phenyl mercuric acetate) in the range of 10 to 100 $\mu g/m^3$ for almost 6 years, yet did not show any symptoms suggestive of mercury intoxication. In fact, several other studies strongly suggest that some organic mercurials, especially the aryl-mercury salts,

are no more toxic than the inorganic mercury salts.[66,103,113,162] This has led several authors to question the TLV of 10 $\mu g/m^3$ for all organic mercury compounds.[73,103,175]

In Russia, an 8-hour MAC of 5 $\mu g/m^3$ was established for alkyl mercury compounds (methyl and ethyl mercury chlorides).[142] An International Symposium recommended 100 $\mu g/m^3$ as the 8-hour MAC for phenyl and methoxyethyl mercury salts.

Therefore, if a 24-hour maximum exposure limit is to be established for organic mercury compounds, it may be necessary to establish different tolerance levels for particular types of organic mercury compounds, such as alkyl and aryl compounds.

3. SOURCES

3.1 Natural Occurrence

Mercury is neither abundantly nor widely distributed in the earth's crust.[122,123] The percentage of mercury in igneous rocks is approximately 10^{-7}. Although less abundant than platinum, uranium, silver, cesium, and other common metals, mercury exists in highly concentrated ores and thus is readily attainable. Most mercury deposits are found near the surface of the earth, and in the United States are confined mainly to the West Coast in a belt of late tertiary orogeny and volcanism.

There are only a few ores of mercury, and only one ore of economic importance--cinnabar, or mercuric sulfide (see Section 3.2). Elemental mercury occurs in small quantities, mixed with its ores.

3.2 Production Sources

The production of mercury in the United States has not kept pace with the consumption since 1918, except for the years 1931, and 1940 through 1942. The total production has fluctuated since 1935 (see Figure 3). In 1950, the domestic production was the lowest ever recorded, supplying only 9 percent of the national requirements. In succeeding years, production gradually increased--reaching a maximum of 83 percent of the consumption--before again declining. Approximately 5.5 million pounds of

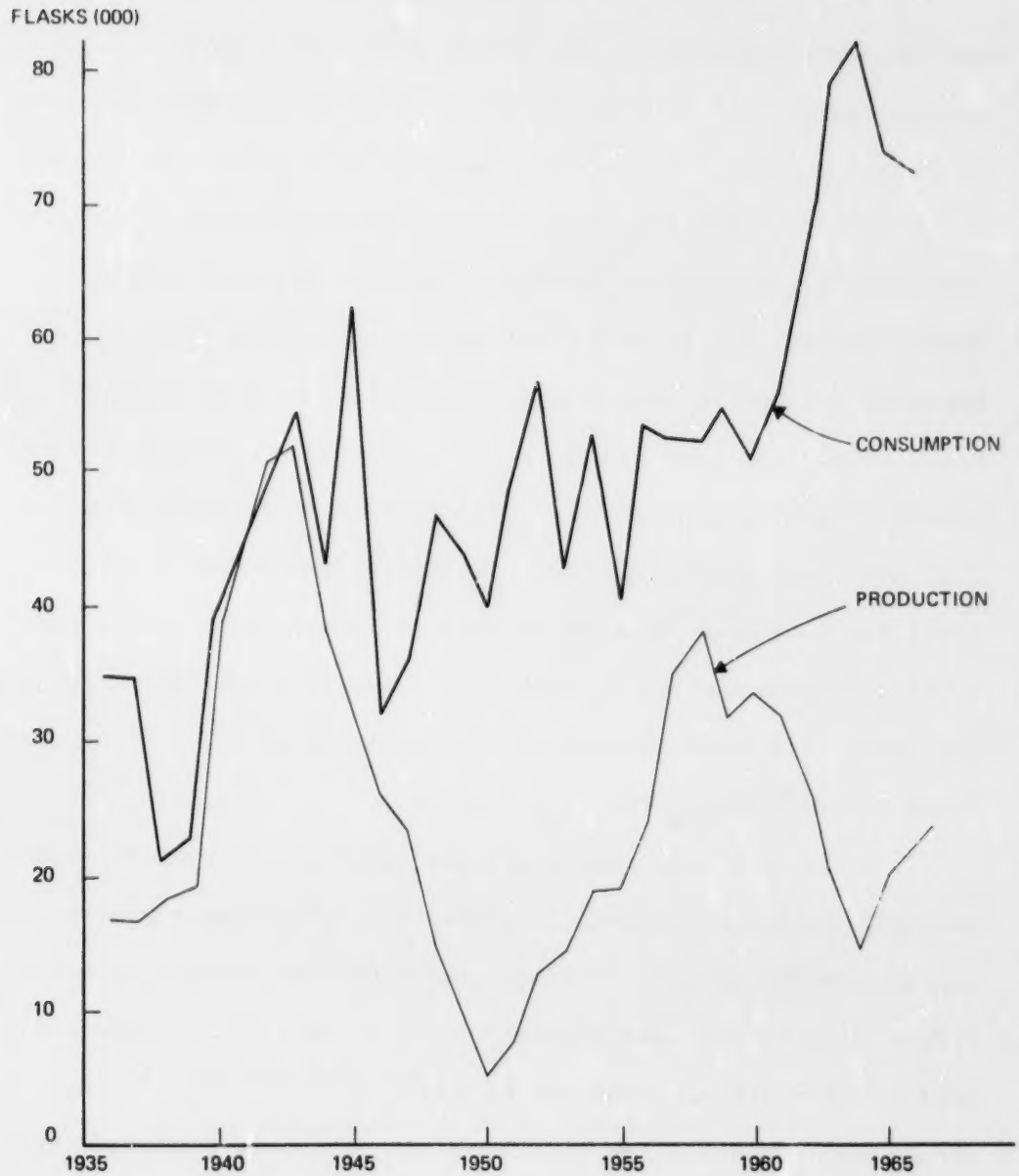

FIGURE 1

U.S. Consumption and Production of Mercury, 1935-66[126]

mercury were consumed in the United States in 1966.[126] Of this amount, about 1.67 million pounds or 30.6 percent were produced by domestic mines. California (with 73.1 percent) and Nevada (with 15.2 percent) are the principal mercury-producing states, with lesser quantities produced in Alaska, Arizona, Arkansas, Idaho, Oregon, Texas, Utah, and Washington. (See Table 6 in Appendix for United States production of mercury by states since 1936.) In 1963, eight mines furnished 97 percent of the domestic primary production. (See Table 7 in Appendix for the list of these mines and their location.) The number of producing mines has increased from 48 in 1963 to 130 in 1966, while 149 mines produced mercury in 1965.[126] Table 8 in the Appendix lists the mines with a production of 100 flasks or more in 1966. Forty other mines[150] supplied the remainder.

The principal ore mined for mercury is cinnabar (red mercuric sulfide, alpha-HgS), which is mined by both underground and surface or open-pit mining. Several studies have been conducted to determine the concentration and hazard of atmospheric mercury in mines all over the world.[4,50,87,104,172,174] Although no data are given on the amount of mercury emitted into the surrounding atmosphere, these studies showed that the working environment contained dangerous amounts of mercury (as high as about 5,000 $\mu g/m^3$) in the form of vapor and aerosols, as well as

in mine dusts. A number of the miners studied exhibited signs of mercury intoxication especially before proper methods of control were used.

Ore refining, which is usually done near the mine site, is another source of atmospheric mercury contamination, as well as an industrial hazard. The ore is heated in retorts or furnaces in the presence of oxygen or lime to liberate mercury as a vapor, which is collected in condensers.[150] These gases are then passed through washers and into the open air through a stack. According to Schuette[146] as cited by Stokinger,[159] stack losses should not exceed 2 or 3 percent, although very much higher losses have occurred. A stack loss of only 3 percent would mean that over 50,000 pounds of mercury were emitted into the atmosphere in the United States in 1966 from smelting alone.

Mercury can also be found in small amounts in associated sulfides of other metals, although it may not be economically feasible to recover the mercury. Hence, in refining the ore to recover other metals, the mercury vapor produced in the process may escape into the atmosphere. In special cases, significant amounts of mercury have been recovered as a by-product of zinc, copper, and gold production.[124]

Due to the large demand and low cost of production rates, the production of secondary mercury has been high. Sources of secondary mercury are reclaimed dental amalgams, oxide and

acetate sludges, battery scrap, and dismantled mercury boilers. About 23 percent of the mercury consumed in 1966 was secondary mercury. In 1964 and 1965 secondary mercury was very high (about 30 and 63 percent respectively of the total mercury production) as a result of the release of surplus mercury by the Atomic Energy Commission.

3.3 Product Sources

In 1963, a total of about 300 companies used the virgin mercury supplied by the mines; 96 percent of this virgin mercury was consumed by 80 companies located in the Eastern States.[150] A list of the large producers, consumers, and dealers in mercury is given in Table 9 in the Appendix. About 400 companies throughout the United States consumed approximately 20 percent of the redistilled mercury in 1963.[150] Consumption appears to be generally increasing and is expected to maintain this trend for the next 5 years or more.[150] Table 10 in the Appendix lists some of the companies producing mercury compounds.

The two major uses of the mercury consumed in the United States in 1966 were in electrical apparatus and electrolytic preparation of chlorine and caustic soda, corresponding to about 19 to 16 percent of the total consumption, respectively.[126] Other uses include paints (11 percent), industrial and control instruments (6 percent), pharmaceuticals (5 percent), agriculture

(3 percent), and catalysts (3 percent). The data for the uses for the past 20 years are given in Table 4 in the Appendix. The trend for consumption by uses can be seen in Figure 2. The use of mercury in agriculture and for industrial and control instruments has declined. However, there is a strong increase in the use of mercury for the electrolytic preparation of chlorine and caustic soda that is further reflected in "other uses," which includes mercury used for installation of new chlorine and caustic soda plants. Mercury is also increasingly used in electrical apparatus, paints, and laboratory products.

Mercury's high specific gravity, electrical conductivity, and boiling temperature, plus the fact that it is a liquid at normal temperatures, make it suitable for application in mercury-arc lamps, neon and fluorescent lamps, mercury boilers, electrodes in electrolysis, arc rectifiers, batteries, switches, thermometers, barometers, manometers, hydrometers, pyrometers, and related equipment.[10,107,121,150] A relatively new application is in amalgam metallurgy and precision casting,[150] such as jewelry and molding processes.[46,93] (See Table 2 in the Appendix for a summary of the properties and uses of mercury.)

The chemical properties of mercury compounds give rise to such applications as catalysts in preparing organic compounds, fungicides, spermicidal jellies, herbicides, insecticides,

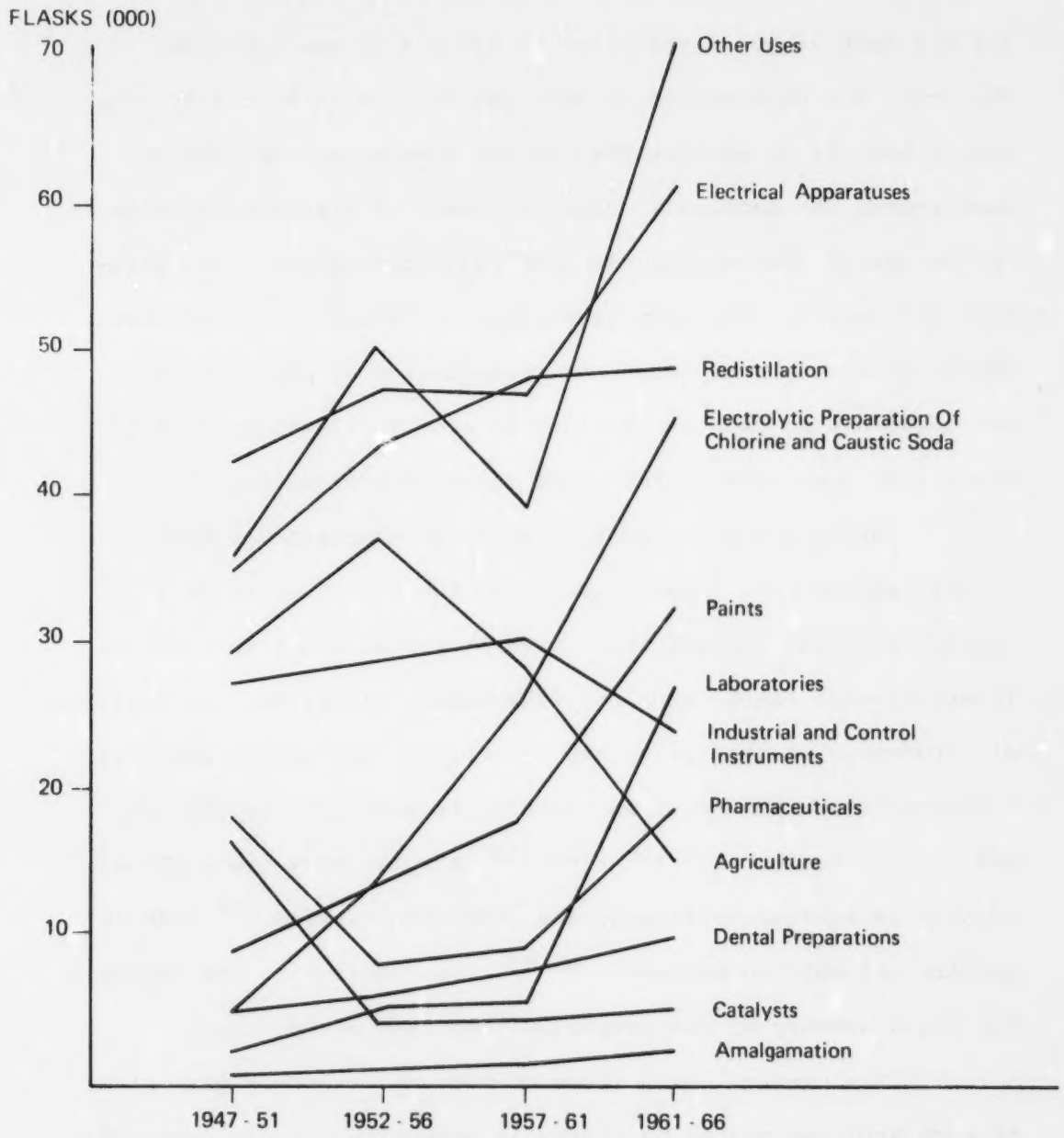

FIGURE 2

Mercury Consumption by Uses, 1947-66

explosives, antiseptics and disinfectants, pigments, preservatives, embalming preparations, antibiotics, diuretics, fireworks, and many other uses. Some of the more common compounds and their uses, along with their physical properties and toxicity, are listed in Table 5 in the Appendix.

Only one example of community-wide mercury poisoning has been reported. Heimann[82] mentioned the incident described by Henderson and Haggard[84] following a fire in a mercury mine in Idrija, Austria (now in Yugoslavia). The community of 900 inhabitants developed the muscular tremors symptomatic of mercury poisoning; moreover, cows and other domestic animals also exhibited the symptoms of intoxication.

Numerous examples in the literature describe the hazards of mercury poisoning resulting from industrial exposure. These hazards are present in a variety of industries, including the manufacture of felt hats (rare),[10] technical instruments,[134,154] chlorine and caustic soda,[115,119] carbon for electrical motors,[15] fluorescent lamps,[107,121] neon signs,[52] mercury compounds,[152] jewelry,[46,93] tungsten rods,[161] textiles,[96] pesticides,[86,88,109] and dry batteries.[176] They also exist in seed-treating,[115] repair of electrical apparatus,[22] mercury catalysis,[69] and occur in rectifier shops[145] and breweries.[35] Broadhurst[32] and Bidstrup[21] have summarized some of the cases of industrial mercury poisoning.

Mercury poisoning is also a problem for the general public. It has been demonstrated that a mercury hazard exists in scientific laboratories,[151] schools,[12,72,101,168] hospitals,[177] medical laboratories,[131] and dental offices.[94,153] Organic mercury compounds used in house paints yield detectable concentrations of mercury (over 100 $\mu g/m^3$ for short periods of time). However, Goldberg and Shapero[70] and Jacobs et al.[90] concluded from their studies that these paints do not constitute a direct hazard to the painters or occupants of the room which was painted.

Other than mercury-containing paints, the only other common household source of poisoning appears to be the breakage of thermometers and possible damage to mercury-filled switches, neither of which apparently constitute a known hazard. There are, however, several exceptional examples of mercury poisoning in the home. Burke and Quagliana[37] reported mercury poisoning resulting from an attempt to recover mercury from hearing-aid mercury batteries. Mathes et al.[116] cited an example where a homemade mercury paint was used on a gas heater. The heater was turned on before the paint was completely dry, resulting in the deaths from mercury vapor inhalation of three children sleeping in an adjacent room. Bucher[36] mentions an incident in which a bottle of mercury was spilled, and although it was "cleaned up" left enough remaining mercury to be harmful.

Mercury vapors are probably the major source of environmental pollution. The hazard from mercury vapor occurs chiefly from spillage in and around the areas where it is used.[29] Biram[23] points out that it is impossible to clear mercury away completely once it has been spilled or splashed. When this happens, the mercury tends to break up into exceedingly small droplets which can become entrapped in cracks and crevices; the amount of vapor produced is thus increased because of the greatly increased surface area of the mercury.

The rate of vaporization for mercury increases very rapidly with increase in temperature. Figure 3 shows that the atmospheric concentration will approximately double for every 10°C increase. It should be noted that at room temperature (20 to 24°C or 68.0 to 75.2°F) the saturation concentration of mercury in air (see Table 3 in the Appendix) is 130 to 180 times greater than the accepted Threshold Limit Value for 8-hour exposure. Hence, it is conceivable that mercury vapor in the environmental air could reach a concentration that would be harmful to the surrounding population and even fatal.

Giese[68] found that at 25°C a stream of air flowing at a rate of one liter per minute over a 10 cm^2 area of mercury becomes about 15 percent saturated (i.e., contains about 3,000 $\mu g/m^3$ of mercury), which is well above the human toxicity level.

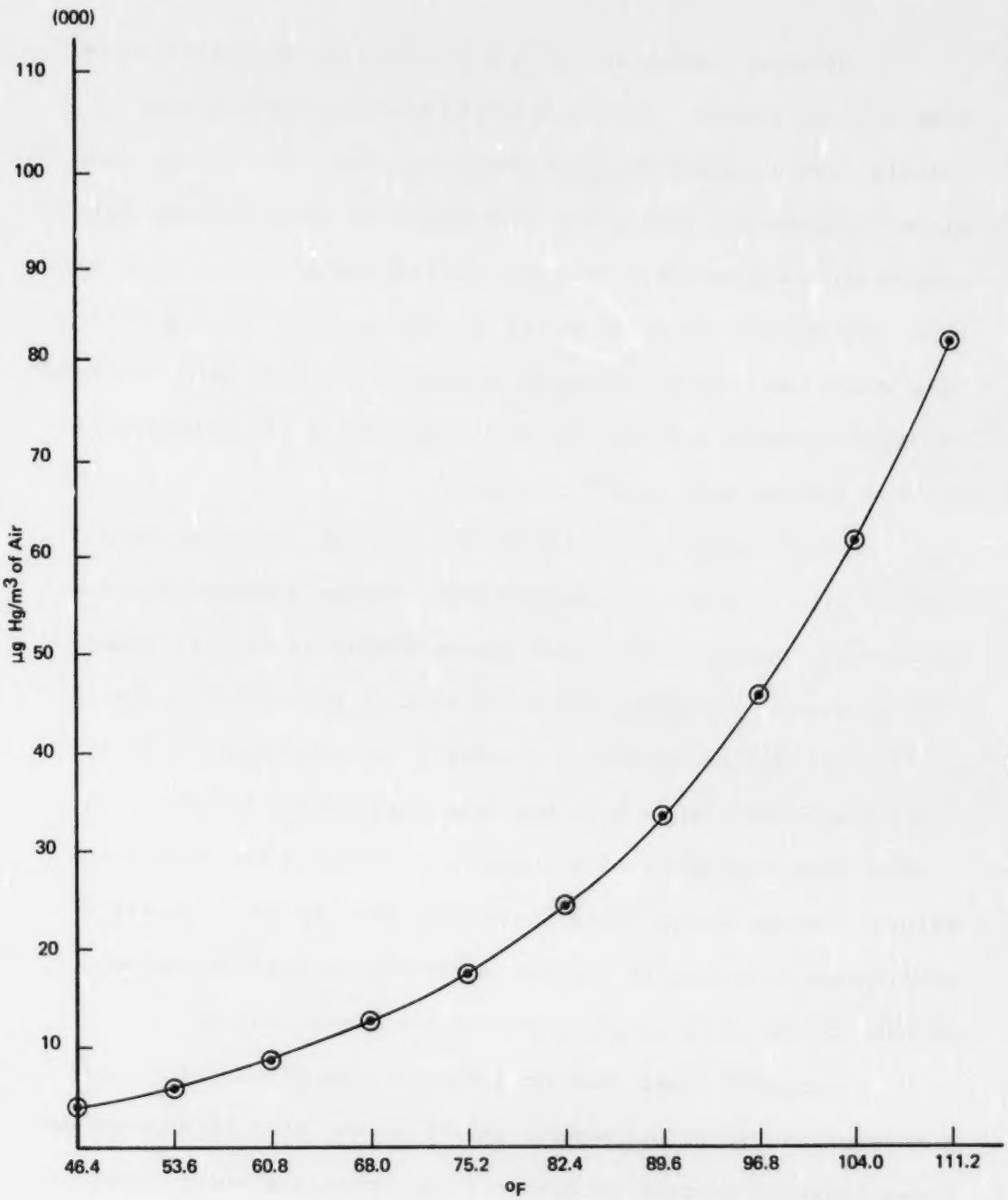

FIGURE 3

Saturation Concentration of Mercury in Air Versus Temperature

The amount of mercury (approximately 10 g) in 10 thermometers used in the home could easily produce a 10 cm^2 area if the mercury from each thermometer formed about 10 or more droplets or globules of mercury. More cases of mercury poisoning probably would occur were it not for the fact (in part) that in still air the heavy vapors (approximately eight to nine times more heavy than air) tend to collect near the surface of the mercury and thus tend to prevent rapid evaporation. Dirt, grease, and other impurities also collect on the surface of the drops, retarding the normal rate of evaporation.

Several foreign countries have problems with mercury pollution today, especially Japan and Sweden. In Japan, large amounts of organic mercury fungicides are being used in the prevention of "rice blast disease." A high concentration of mercury in the air has resulted, and an even higher one in food and water. Air measurements have shown that the concentration of mercury is as high as 10,000 $\mu g/m^3$ in some areas.[63] In Sweden,[3] the mercury comes from such industrial sources as pulp and paper and chloralkali plants.

3.4 Environmental Air Concentrations

Only one paper giving data on the concentration of mercury in the air has been found. Cholak[41] reported the mercury content of suspended particulate matter for two cities:

	Concentration in $\mu g/m^3$	
	Average	Range
Cincinnati (1946-1951)	0.10	0.03-0.21
Charleston (1950-1951)	0.17	

These data pose this important question: how hazardous is the mercury contained in particulates? The question is yet to be answered. All studies found concerning the inhalation of either mercury vapor or its compounds deal with the pure substance and not mercury-containing particulates. Furthermore, not only do the data represent an inadequate sampling of the United States, they also fail to give the current concentrations or illustrate trends for the future.

Dr. L. J. Goldwater[71] in 1968 kindly provided the following unpublished data on some recent surveys of mercury concentration:

	Concentration of Mercury ($\mu g/m^3$)
Palo Alto, Calif. (Hg vapor)	0.001 - 0.01
New York, N.Y. (Hg in particulates)	Outdoor: 1-14 Indoor: 1-41

The New York data are from 25 to 30 samples taken about 1960 over a three month period in the Queens section of New York City, primarily from the residential district, although some of the indoor samples were taken in business offices and the laboratories and offices of Columbia University. As far

as could be determined, there were no unusual sources of mercury near the sampling areas.[71] The Palo Alto data are from representative samples collected over several years.[71]

4. ABATEMENT

Industries using mercury and mercury-related compounds have developed control methods as a result of two principal factors: the high toxicity of most mercury sources and the high cost of mercury. Industries that use mercury are divided into two main categories: those that use mercury at ambient temperatures and those that use mercury at elevated temperatures. For the former, control methods consist largely of protection of the employees by maintaining proper ventilation in work areas, cleaning up spilled mercury, and using non-porous material for floors, working surfaces, and protective clothing.[56] Low concentrations of mercury vapor are directly vented to the open atmosphere with no attempt to trap the mercury vapors.

When mercury is used at elevated temperatures in such uses or processes as metallurgy of mercury and other metals (via amalgamation with mercury), mercury boilers, and mercury-arc rectifiers, better control of the effluent mercury vapors is necessary. In general practice, vapors are condensed by means of cold-water-jacketed condensers.[70] In one instance, impregnated charcoal was used to remove mercury from the hydrogen gas stream originating from mercury cells used in the production of hydrogen.[105] More effective removal can be accomplished by use of water scrubbers in the final section of the condensers and by

subsequent use of a pyrolusite adsorber.[137]

Spilled mercury presents another possible pollutant problem. This problem occurs not only in industry, but also in schools and hospitals, laboratories, and even homes (from the breakage of thermometers, etc.). The ambient atmosphere as well as the working environment are continually being contaminated by these sources. Because of lack of knowledge or lack of concern about the toxicity of mercury, the mercury is often not removed effectively, if at all. Several removal methods are available, ranging from sweeping with special vacuum cleaners to chemical treatment of the mercury. Sweeping can effectively remove large droplets but is not adequate for removing mercury trapped in small crevices of the walls and floors. Yavorovskaya[180] developed a method which although more effective, can only be used on surfaces covered with thermostable materials. The apparatus consists of an electric heating chamber (which heats the surface to be cleaned), a blower, and a collector-filter containing iodide-activated charcoal. Heating the surface to be cleaned to about 200°C vaporizes the mercury, which is then carried by the air stream into the collection filters.

In chemical removal methods, a substance is applied which will react readily with mercury at ambient temperatures to form a nearly nonvolatile mercury compound, which can then

be swept up. The substances generally used are inorganic polysulfides[12,176] or powdered sulfur.[45] A study conducted by Copplestone and McArthur[45] on various such substances and mixtures noted that two of the most effective treatment mixtures were (1) sulfur, calcium oxide and water, or (2) commercial aerosol hair spray.

Thus, effective methods have been developed to control mercury vapors, although they are not always applied because of ignorance or lack of concern about the toxicity of mercury.

Other mercury compounds which may cause air pollution are those used in pesticides, especially those used to spray crops or weeds. No particular methods of control are used other than those for the normal control of pesticides.

5. ECONOMICS

No information has been found on the economic costs of mercury vapor or mercury compound air pollution or on the costs of its abatement.

Data on the production and consumption of mercury and its compounds are presented in Section 3.

6. METHODS OF ANALYSIS

Various methods have been developed to measure mercury vapor and mercury particles in the atmosphere. Portable continuous monitoring detectors for mercury vapor are available from several companies (Beckman Instruments, Inc.; General Electric Co.; Sunshine Scientific Instruments, Inc.; etc.). These detectors are based on the principle that ultraviolet light at 2537 Å is strongly absorbed by mercury vapor.[160,178] Thus, any other vapor which also absorbs light at 2537 Å or affects the accuracy of the measurement of the light intensity (such as fogs, dust, and smoke) can cause interference and produce unreliable results. Many compounds do absorb light in this range (ozone, carbon dioxide, and aromatic hydrocarbons, for example). Since their sensitivity is much less, however, a high concentration is necessary to interfere with mercury vapor detection (generally a concentration about 100 to 100,000 times greater than that of mercury). The lower sensitivity of these instruments is in the range of 5 to 10 $\mu g/m^3$ with about 2 percent full-scale accuracy.

Battery-operated vapor detectors have been described by McMurry and Redmond[120] and also by Jacobs and Jacobs.[91] Use of these detectors at concentrations of mercury above 1,000 $\mu g/m^3$ of air requires recalibration. An apparatus was designed by Nelson *et al.*[130] to facilitate the calibration of these detectors.

Systems have also been developed for use when other vapors which absorb at 2537 Å are present in concentrations high enough to cause serious interference. A specific system for mercury was reported recently by Hawkes and Williston,[81] and also by James and Webb.[92] Their approaches are basically similar: the air sample is split into two portions and each air stream is passed through identical absorption cells. One of the cells is preceded by a material which removes the mercury vapor from the air stream, and the difference in absorption values between the two cells is a measure of the mercury vapor.

Barringer[9] developed a method to measure mercury vapor in free-standing air which is based on absorption of light at 2537 Å. By taking advantage of the pressure-broadening of the mercury emission lines, the interference due to other compounds is minimized.

Techniques have been developed which can detect lower concentrations of mercury vapor than those mentioned although they do not continuously monitor. The basic approach is to collect the vapor on absorbing materials such as gold,[173] silver,[173] or paper impregnated with potassium iodide,[83] and then release it into an ultraviolet detector system. A portable instrument is being developed--using the initial absorption of mercury on gold--which will be able to detect mercury vapor in the picogram range (10^{-12}g) in the atmosphere.[71]

Mercury vapor can be detected by using indicator papers (such as copper iodide paper,[51] selenium sulfide paper,[13,132] or selenium paper[158]), gold chloride on silica gel,[78] or commercially available gas-detecting tubes.[102] All of these methods are quick and simple but not very sensitive (they can generally detect about 500 to 1,000 $\mu g/m^3$ of mercury with approximately $\pm 5\%$ accuracy). They could be useful for detecting vapor leaks, however.

Recently a radiochemical method was developed for the detection of mercury vapor. This method is based on isotope exchange that takes place when the vapors are passed through a solution of ^{203}Hg-mercuric acetate.[110]

Several methods are available for the determination of mercury in biological materials, such as photometric,[171] neutron activation,[133] spectrographic[47] and chemical[42] techniques.

Numerous chemical methods have been described for the determination of mercury vapor, mercury in dust, and both organic and inorganic mercury compounds. The chemical procedures consist of collecting the mercury-containing material in impingers containing water,[38,111] alcohol,[38,111] potassium permanganate-sulfuric acid,[97,108,114,141] potassium permanganate-nitric acid,[6] or iodine-potassium iodide solution.[111] Trapping is possible with iodide-activated charcoal and mineral wool.[148]

The final determination is usually made colorimetrically with dithizone,[38,141] di-beta-naphthyl-thiocarbazone,[108] or Reyneke salt.[6] The final determination can also be done by means of electrolysis[38] or the use of selenium sulfide paper.[148] If 100 liters of air are passed through the collection media, the limit of detection is about 1 to 10 $\mu g/m^3$ of mercury, with $\pm 5\%$ accuracy. The final mercury determination is usually done in a laboratory. Kudsk,[97] however, has developed an on-site method of determination with a sensitivity of about 1 µg of mercury. By careful control of the acidity of the solutions, interference from other metals is greatly minimized and causes no problems in most cases. However, problems do arise with certain organo-mercury compounds, especially the dialkyl derivatives.[106,139] Linch *et al.*[106] found that a collection medium of iodine monochloride in acid gave excellent recovery of dimethyl and diethyl mercury. Quino[139] found isopropyl alcohol to be an effective medium for collection of dibutyl mercury. The latter has also developed a simple, rapid method for the determination of dialkyl mercury compounds (by reaction with bromine followed by reaction with ditolyl mercury and dithizone) that can be used in the field with a sensitivity of about 500 $\mu g/m^3$ of mercury--or if determined in the laboratory, about 2 to 12 µg of the mercury compound.

Hamilton and Ruthven[79] reported a technique which provides a continuous monitoring of combined mercury vapor and organo-mercury compounds. The technique consists of pyrolyzing the compounds to free mercury vapor, which is then detected by a spectrophotometer. By determining the mercury vapor content of the air, the amount of organic mercury can then be found by difference.

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APPENDIX

TABLE 1

SUMMARY OF MERCURY TOXICITY DATA VIA INHALATION[159]

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SYMPTOMS AND EFFECTS	COMMENTS
ACUTE POISONING	
Metallic taste, nausea, abdominal pain, vomiting, diarrhea, headache, and sometimes albuminuria; after a few days the salivary glands swell, stomatitis and gingivitis develop, teeth may loosen, and ulcers may form on lips and cheeks. In addition, organic mercury derivatives irritate mucous membranes, producing sensation of dryness and irritation in the nasopharynx and mouth. Very high exposures result in tightness and pain in the chest, difficulty in breathing, and coughing. Later stages characterized by hemolysis, sleeplessness, headache, facial tics, tremor of the digits, deliriousness, and hallucinations	Relatively infrequent; in milder cases recovery occurs in 10-14 days, although chronic poisoning symptoms may ensue, accompanied by muscular tremors and psychic disturbances. In severe poisoning the physical defects and mental deterioration may continue. Death is frequent in very severe cases as a result of extreme exhaustion. 1,200 to 8,500 μg Hg/m^3 of air have resulted in acute poisoning
CHRONIC POISONING	
Psychic and emotional disturbances (irritable, irascible especially when criticized, unable to concentrate, fearful, indecisive, or depressed). Headache, fatigue, weakness, loss of memory, and either drowsiness or insomnia. Tremors affecting hand, head, lips, tongue, or jaw; writing affected. Other neurological disturbances include paresthesia, affections of taste or smell, neuralgia, and dermographism. Renal disease. Chronic nasal catarrh and epistaxis. Salivation, gingivitis, and digestive disturbances. Ocular lesions, amblyopia, and narrowing of vision, the latter particularly from organic compounds	May appear after a few weeks of exposure, or delayed much longer. Organic mercury symptoms are confined more specifically to the nervous system. Slow recovery on removal from exposure. Organic mercury compounds mainly affect the motor and sensory nerves; symptoms of salivation, stomatitis, and erethism are more pronounced in exposure to the inorganics

APPENDIX

TABLE 2

PROPERTIES AND USES OF MERCURY[172]

Atomic Symbol: Hg

Molecular Weight: 200.59

Isotopes: 202 (29.6%), 200 (20.3%), 199 (17.0%), 201 (13.2%), 198 (10.1%), 204 (6.7%), 196 (0.15%).

Physical Properties: Silver white liquid at normal ambient temperatures; high density (13.5939 at 20°C); high surface tension (480.3 dyn/cm); slightly volatile at ordinary temperature (see Table 3 and Figure 2); heat of fusion 2.82 cal/g; heat of vaporization 65 cal/g; solidifies at -39°C to a tin-white, ductile, malleable mass; boiling point 356.9°.

Toxicity, Human: Readily absorbed via respiratory tract (elemental mercury vapor, mercury compound dusts), intact skin, and gastrointestinal tract, although occasional incidental swallowing of metallic mercury is without harm. Spilled and heated elemental mercury is particularly hazardous. Acute: soluble salts have violent corrosive effects on skin and mucous membranes; severe nausea, vomiting, abdominal pain, bloody diarrhea; kidney damage; death usually within 10 days. Chronic: inflammation of mouth and gums; excessive salivation, loosening of teeth; kidney damage; muscle tremors, jerky gait, spasms of extremities; personality changes, depression, irritability, nervousness. Phenyl and alkyl mercurials can cause skin burns and be absorbed by the skin. Burning sensation is delayed several hours and thus gives no warning. Alkyls have affinity for brain tissue and may cause permanent damage. Phenyls are no more toxic than inorganic mercury.

Uses: In barometers, thermometers, hydrometers, pyrometers; in mercury-arc lamps producing ultraviolet rays; in switches, fluorescent lamps; in mercury boilers; in manufacture of all mercury salts, mirrors; as catalyst in oxidation of organic compounds; for extracting gold and silver from ores, for making amalgams, electric rectifiers, mercury fulminate; also in dentistry; in determining nitrogen by Kjeldahl method, for Millon's reagent; as cathode in electrolysis, and many other uses. Also in pharmaceuticals, agricultural chemicals, anti-fouling paints.

APPENDIX

TABLE 3

SATURATION CONCENTRATION OF MERCURY IN AIR AT VARIOUS TEMPERATURES*

Temperature °C	Temperature °F	Pressure (mm)	Mercury Concentration ($\mu g/m^3$)
-28	-18.4	.0000063	80
-10	14.0	.0000606	740
0	32.0	.000185	2,180
4	39.2	.000276	3,210
8	46.4	.000406	4,650
10	50.0	.000490	5,880
12	53.6	.000588	6,640
16	60.8	.000846	9,430
20	68.0	.001201	13,200
24	75.2	.001691	18,300
28	82.4	.002359	25,200
30	86.0	.002777	29,500
32	89.6	.003261	34,400
36	96.8	.004471	46,600
40	104.0	.006079	62,600
44	111.2	.008200	83,300
48	118.4	.01098	110,000
50	122.0	.01267	126,000
70	158.0	.04825	453,000
100	212.0	.2729	2,360,000
200	372.0	17.287	118,000,000
300	572.0	246.80	1,390,000,000
400	752.0	1,574.1	7,530,000,000

*The saturation concentration of mercury in air given in the table was calculated from the mercury vapor pressure data. Two assumptions were necessary to make the calculation: (1) that the atmospheric pressure is equal to 760 mm, and (2) that mercury vapor behaves as an ideal gas or that it obeys the ideal gas equation:

$$PV = nRT$$

where P = pressure
V = volume
n = moles of mercury vapor
T = temperature
R = gas constant = 0.06236 $\frac{(mm)\ (m^3)}{(^oK)\ (mole)}$.

The concentration of mercury can be calculated by:

$$\frac{\mu g}{m^3} = \frac{(\text{moles Hg in air})\ (\text{mol wt Hg})\ (10^6)}{\text{volume of air in } m^3}$$

$$= \frac{n_{Hg} \times 200.6 \times 10^6}{V} = \frac{P_{Hg} \times 200.6 \times 10^6}{RT}$$

$$= \frac{P_{Hg}}{T} \times 3.216 \times 10^9$$

where P_{Hg} is vapor pressure of mercury in mm and T is in ^oK or $273+^oC$.

APPENDIX

TABLE 4

MERCURY CONSUMED IN THE UNITED STATES BY USES, 1947-1966[126]

(Flasks[a] in thousands)

Uses	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Agriculture (includes fungicides and bactericides)	5.6	7.1	4.7	4.5	7.7	5.9	6.9	7.7	7.4	9.9
Amalgamation	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Catalysts	5.1	3.3	2.5	2.7	2.6	1.1	0.8	0.6	0.7	0.9
Dental preparations	0.8	1.0	1.0	1.5	0.8	1.3	1.1	1.4	1.2	1.3
Electrical apparatuses	6.8	6.5	7.3	12.1	10.3	8.0	9.6	10.8	9.3	9.8
Electrolytic preparation of chlorine and caustic soda	0.7	0.8	0.8	1.3	1.5	2.5	2.4	2.1	3.1	3.4
General laboratory use, commercial	b	b	b	b	b	b	b	b	b	b
General laboratory use, government	b	b	b	b	b	b	b	b	b	b
General laboratory use, total	0.3	0.4	0.3	0.7	0.5	0.6	1.2	1.1	1.1	1.0
Industrial and control instruments	5.4	5.7	5.0	5.4	6.2	6.4	5.6	5.2	5.6	6.1
Paint, antifouling	0.8	1.0	1.7	3.1	2.5	1.2	0.7	0.5	0.7	0.5
Paint, mildew-proofing								b	b	b
Paper and pulp manufacture								c	c	c
Pharmaceuticals	3.1	3.4	3.4	6.0	2.8	1.4	1.9	1.8	1.6	1.6
Fulminate for munitions and blasting caps	0.5	0.4	0.2	0.3	0.5	0.3	0.0	0.1	0.1	
Redistilled	4.7	6.5	6.6	7.6	8.8	7.6	7.8	9.3	9.6	9.5
Other	1.8	10.2	6.2	3.9	12.5	6.4	14.1	1.9	16.7	10.0
Total	35.6	46.3	39.9	49.2	56.9	42.6	52.3	42.8	57.2	54.1

(continued)

APPENDIX

TABLE 4 (Continued)

MERCURY CONSUMED IN THE UNITED STATES BY USES, 1947-1966[126]
(Flasks[a] in thousands)

Uses	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Agriculture (includes fungicides and bactericides)	6.3	6.3	3.2	3.0	10.1	4.3	2.5	3.1	3.1	2.4
Amalgamation	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.7	0.5	0.5
Catalysts	0.9	0.8	1.0	1.0	0.7	0.9	0.6	0.7	0.9	1.9
Dental preparations	1.4	1.7	1.8	1.8	1.1	2.0	2.4	2.6	1.6	1.4
Electrical apparatuses	9.2	9.3	8.9	9.3	10.3	11.6	11.1	10.7	13.9	13.6
Electrolytic preparation of chlorine and caustic soda	4.0	4.6	5.8	6.2	6.0	7.3	8.0	9.6	8.8	11.5
General laboratory use, commercial	b	b	b	b	1.2	1.8	1.2	1.5	1.1	1.6
General laboratory use, government	b	b	b	b			3.8	17.0		
General laboratory use, total	0.9	1.0	1.1	1.3	1.2	1.8	5.1	18.5	1.1	1.6
Industrial and control instruments	6.0	6.1	6.2	6.5	5.6	5.2	4.9	5.0	4.6	4.3
Paint, antifouling	0.6	0.8	1.0	1.4	3.1	0.1	0.3	0.6	0.3	0.1
Paint, mildew-proofing	b	b	2.5	2.9	b	4.6	6.4	4.9	7.5	7.8
Paper and pulp manufacture	c	c	4.4	3.5	b	2.6	2.8	2.2	0.6	0.6
Pharmaceuticals	1.8	1.4	1.7	1.7	2.5	2.4	4.1	5.1	3.3	3.7
Fulminate for munitions and blasting caps										
Redistilled	9.7	9.5	9.3	9.7	9.0	9.0	9.2	11.4	12.0	7.0
Other	11.0	11.0	7.7	2.7	6.0	12.4	20.3	7.7	15.4	15.6
Total	52.9	52.6	54.9	51.2	55.8	65.3	78.0	82.6	73.6	72.0

[a]1 Flask = 76 lb.
[b]Data not available.
[c]Included with agriculture.

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg	mp°C bp°C	Toxicity	Uses
Ammoniated mercuric chloride (mercuric ammonium chloride) $HgNH_2Cl$	252.09 79.58	Infusible	See mercury	As topical anti-infective
Mercuric bromide $HgBr_2$	360.44 55.66	237	See mercury	As laboratory reagent
Mercuric chloride (Corrosive sublimate) $HgCl_2$	271.52 73.88	282 (3)	LD_{50} for rats, orally 37 mg/kg	For preserving wood, embalming, disinfecting, etching metals, tanning leather, as ink for mercurography, in treating seed potatoes, as topical antiseptic
Mercuric cyanide $Hg(CN)_2$	252.65 79.40	Decomposes	Violent poison	As topical antiseptic, antisyphilitic
Mercuric fluoride HgF_2	238.61 84.07	645 (650)	See mercury and fluorine	In fluorination of organic compounds
Mercuric fulminate $Hg(NCO)_2$	284.65	Explosive		In detonators
Mercuric iodide HgI_2	454.45 (44.14)	259 (350)	See mercury	As Nessler's Reagent, topical antiseptic, local counter-irritant and vesicant for horses

(continued)

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg	mp °C bp °C	Toxicity	Uses
Mercuric nitrate $Hg(NO_3)_2 \cdot H_2O$	342.64	70	See mercury	In manufacture of felt, mercury fulminate, destruction of phylloxera
Mercuric oxide (red) HgO	216.61 92.61	Decomposes at 500	See mercury	As topical antiseptic, paints for ships' bottoms; for diluting pigments; in batteries; as reagent in quality determinations
Mercuric sulfate $HgSO_4$	296.68 (67.62)	Decomposes		As electrolyte for primary batteries, in metallurgy of gold and silver
Mercuric sulfide (cinnabar) HgS	232.68	Sublimes at 583.5	See mercury	As pigment for horn, rubber, plastics, sealing wax, colored papers, linen marking
Mercuric thiocyanate $Hg(SCN)_2$	316.79 63.33%	Decomposes	See mercury	In fireworks; as intensifier in photography
Mercurous chloride Hg_2Cl_2	472.09 84.98%	Sublimes at 400-500	Low mammalian toxicity; 210 mg/kg (in rats) caused mercurial symptoms	For dark-green Bengal lights, calomel paper, when mixed with gold in painting on porcelain, calomel electrodes, as fungicide, in agriculture to control root maggots. Med. use: as cathartic, diuretic, antiseptic
Mercurous sulfate Hg_2SO_4	497.29 80.68%	Decomposes		In making electric batteries

(continued)

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg	mp °C bp °C	Toxicity	Uses
Diethyl mercury $Hg(C_2H_5)_2$	258.73	159		As fungicide, herbicide
Dimethyl mercury $Hg(CH_3)_2$	230.68	(95)		As fungicide, herbicide
Ethyl mercuric chloride C_2H_5HgCl	265.13 75.66%	192	Highly toxic; see mercury	As fungicide for treating seeds
Mercuric acetate $Hg(C_2H_3O_2)_2$	318.70 62.95	Decomposes	See mercury	In mercuration of organic compounds, absorption of ethylene
Mercuric benzoate $Hg(C_6H_5CO_2)_2 \cdot H_2O$	460.85 43.53			In treatment of syphilis and gonorrhea
Mercuric lactate $(CH_3CHOHCOO)_2Hg$			Acute oral LD_{50} for rats 200 mg/kg	As fungicide
Mercuric oleate $Hg(C_{17}H_{33}CO_2)_2$	763.53 26.29			As topical parasiticide
Mercuric sodium p-phenosulfonate $Hg(C_6H_4SO_3Na)_2$	590.92 33.95		See mercury	As germicide in soaps and lotions (1:100), local antiseptic

(continued)

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg	mp °C bp °C	Toxicity	Uses
Mercurin $C_{14}H_{25}HgNO_5$	487.97 41.11%			As diuretic
Mercurophen $C_6H_4Hg\ NNaO_4$	377.70 53.11%		See mercury	Med. and vet. use: As local antiseptic, surgical instrument disinfectant
Mercurous acetate $Hg_2(CH_3COO)_2$	519.31 77.26%			Med. use: formerly in syphilis treatment
Methyl mercuric chloride CH_3HgCl	251.10	170 Volatile at 100		As fungicide
Methyl mercuric propionate $CH_3HgO_2CC_2H_5$				As fungicide, antibiotic; in seed treatment
Methyl mercuric dicyaniamide $CH_3HgC_2H_3N_4$		156-157	High mammalian toxicity (internal and on skin contact)	As fungicide, in seed treatment
Methyl mercuric nitrile CH_3HgCN		95	High mammalian toxicity; vesicant	As fungicide, in seed treatment

(continued)

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg	mp °C bp °C	Toxicity	Uses
Methyl mercuric pentachlorophenate $CH_3HgOC_6Cl_5$		192	Acute oral LD_{50} for rats 56 mg/kg	As fungicide, in seed treatment
Methyl mercuric quinolinolate $CH_3HgOC_9H_6N$		133-137	Acute oral LD_{50} for rats 72 mg/kg	As fungicide, in seed treatment
Phenylmercuric acetate $C_6H_5HgOOCCH_3$	336.75 59.57%	149	High mammalian toxicity; oral LD_{50} for rats 40 mg/kg	As herbicide, fungicide
Phenylmercuric benzoate $C_6H_5HgO_2C_7H_5$		95-99	High mammalian toxicity	As fungicide
Phenylmercuric chloride C_6H_5HgCl	313.18 64.06%	250-252	See mercury; high mammalian toxicity	As antiseptic, fungicide. Med. use: as external local antiseptic
Phenylmercuric hydroxide C_6H_5HgOH		Decomposes at 200	High mammalian toxicity	As fungicide
Phenylmercuric nitrate, basic $C_6H_5HgOH \cdot C_6H_5HgNO_3$	634.45 63.24%	Decomposes at 187-190	See mercury; subcutaneous LD_{50} for rats 63 mg/kg	As fungicide

(continued)

APPENDIX

TABLE 5. PROPERTIES AND USES OF SOME MERCURY COMPOUNDS[80,121]

Compound	Mol. Wt. % Wt. Hg.	mp °C bp °C	Toxicity	Uses
Phenylmercuric salicylate $C_6H_5HgO_2C-C_6H_4OH$		155-161	High mammalian toxicity	As fungicide
Phenylmercuric borate $(C_6H_5Hg)_2HBO_3$	338.56 59.25%	112-113	See mercury; Much less toxic than most mercurial compounds	As local external antiseptic

APPENDIX

TABLE 6

U.S.A. PRODUCTION OF MERCURY BY STATES (1936-1956)[124,126]
Flasks (1 Flask = 76 lb)

Year	Alaska	Calif.	Idaho	Nevada	Oregon	All Other	U.S.A.
1966	*	16,070	1,134	3,355	700	749	22,008
1965	*	13,404	1,119	3,333	1,364	362	19,582
1964	303	10,291	83	3,262	126	77	14,142
1963	400	13,592	*	4,944	*	181	19,117
1962	3,719	15,951	*	6,573	*	34	26,277
1961	3,743	18,688	*	7,486	*	1,745	31,662
1960	4,459	18,764	*	7,821	513	1,666	33,223
1959	3,743	17,100	*	7,156	1,224	2,033	31,256
1958	3,380	22,365	*	7,336	2,276	2,710	38,067
1957	5,461	16,511	2,260	6,313	3,993	87	34,625
1956	3,280	9,017	3,394	5,859	1,893	734	24,177
1955	(1,000)	9,875	1,107	5,750	1,056	167	18,955
1954	1,046	11,262	609	4,974	489	163	18,543
1953	40	9,290	*	3,254	648	1,105	14,337
1952	28	7,241	887	3,523	868		12,547
1951		4,282	357	1,400	1,177	77	7,293
1950		3,850		680	5		4,535
1949	100	4,493		4,170	1,167		9,930
1948	100	11,188	543	1,206	1,351		14,388
1947	127	17,165	886	3,881	1,185		23,244
1946	699	17,782	868	4,567	1,326	106	25,348
1945	*	21,199	62	4,338	2,500	2,664	30,763
1944	*	28,052	*	2,460	3,159	4,017	37,688
1943	786	33,812	4,261	4,577	4,651	3,842	51,929
1942	*	29,906	*	5,201	6,935	8,804	50,846
1941	*	25,714	*	4,238	9,032	5,937	44,921
1940	162	18,629	*	5,924	9,043	4,019	37,777
1939		11,127	*	828	4,592	2,086	18,633
1938		12,277		336	4,610	768	17,991
1937		9,743		198	4,264	2,303	16,508
1936		8,693		211	4,126	3,539	16,569

*Included in All Other.

APPENDIX

TABLE 7

MAJOR MERCURY MINES* IN 1963 AND THEIR LOCATIONS[150]

Mine	County	State
Red Devil	Aniak District	Alaska
National	Maricopa	Arizona
New Idria	San Benito	California
Buena Vista	San Luis Obispo	California
New Almaden	Santa Clara	California
Culver-Baer	Sonoma	California
Cordero	Humboldt	Nevada
Ione	Nye	Nevada

*These eight mines accounted for 97% of the domestic primary production in 1963.

APPENDIX

TABLE 8

LIST OF MAJOR MERCURY-PRODUCING MINES IN 1966[126]

Mines Producing More Than 1,000 Flasks*

Mine	County	State
Cordero	Humboldt	Nevada
Little King	Kings	California
New Idria	San Benito	Califcrnia
Buena Vista	San Luis Obispo	California
Mt. Jackson	Sonoma	California
Idaho-Almaden	Washington	Idaho

Mines Producing 500 to 1,000 Flasks

Mines	County	State
Gibraltar (Sunbird)	Santa Barbara	California
New Almaden	Santa Clara	California
Socrates	Sonoma	California
Black Butte	Lane	Oregon

Mines Producing 100 to 500 Flasks

Mine	County	State
B & B	Esmeralda	Nevada
Brinkerhoff (Loretta)	Pershing	Nevada
Kitten Springs	Pershing	Nevada
Mt. Diablo	Contra Costa	California
Tehachapi (Walabu)	Kern	California
Knoxville	Napa	California
North Star	San Benito	California
Guadalupe	Santa Clara	California
Altoona	Trinity	California
White Mountain	Aniak	Alaska
Big Sam	Maricopa	Arizona
Pine Mountain	Maricopa	Arizona
Fresno	Presidio	Texas
Bretz	Malheur	Oregon

*Flask = 76 lb.

APPENDIX

TABLE 9

DIRECTORY OF SELECTED PRODUCERS, CONSUMERS, AND DEALERS OF MERCURY[136]

LARGE PRODUCERS

Alaska:
Decoursey Mountain Mining Co., P.O. Box 442, Anchorage.
California:
Harold Biaggini, Atascadero.
COG Minerals Corp., Denver Club B, Denver, Colo.
New Idria Mining & Chemical Co., P.O. Box 87, Idria.
Sonoma Quicksilver Mines, Inc., Guerneville.
Idaho:
Holly Minerals Corp., 340 Third St., N.W., Albuquerque, N. Mex.
Rare Metals Corp. of America, 10th Floor, First Security Bldg., Salt Lake City, Utah.
Nevada:
Cordero Mining Co., 131 University Ave., Palo Alto, Calif.
Oregon:
Arentz-Comstock Mining Venture, 870 First Security Bldg., Salt Lake City, Utah.
Bonanza Oil & Mine Corp., Sutherlin.

LARGE CONSUMERS

The Adams & Westlake Co., Elkhart, Ind.
Allied Chemical Corp., National Aniline Div., 40 Rector St., New York, N.Y.
Allied Chemical Corp., Solvay Process Div., P.O. Box 271, Syracuse, N.Y.
American Cyanamid Co., 30 Rockefeller Plaza, New York, N.Y.
American Meter Co., Erie, Pa.
American Meter Co., 1300 Industrial Blvd., Dallas, Tex.
B I F Industries, Inc., P.O. Box 1342, Providence, R.I.
Bailey Meter Co., 1052 Ivanhoe Road, Cleveland, Ohio.
J.T. Baker Chemical Co., Phillipsburg, N.J.
F.W. Berk & Co., Inc., Park Place East, Wood Ridge, N.J.
Buckman Laboratories, Inc., Memphis, Tenn.
Carbide & Carbon Chemicals Co., A Div. of Union Carbide & Carbon Co., 300 Madison Ave., New York, N.Y.
Carbide & Carbon Chemicals Co., A Div. of Union Carbide & Carbon Co., Niagara Falls, N.Y.
L.D. Caulk Co., Milford, Del.
Cooper-Hewitt Electric Co., 410 8th St., Hoboken, N.J.
E.I. du Pont de Nemours & Co., Inc., 1007 Market St., Wilmington, Del.
Eastern Smelting & Refining Co., 107-109 W. Brookline St., Boston, Mass.
Thomas A. Edison, Inc., Primary Battery Div., Bloomfield, N.J.
Foxboro Co., Foxboro, Mass.
General Aniline & Film Corp., Dyestuff & Chem. Div., P.O. Box 12, Linden, N.J.

(continued)

TABLE 9 (Continued)

DIRECTORY OF SELECTED PRODUCERS, CONSUMERS, AND DEALERS OF MERCURY[136]

LARGE CONSUMERS

General Color Co., Inc., 24 Avenue B, Newark, N.J.
General Electric Co., Purchasing Dept., 1 River Rd., Schenectady, N.Y.
Gulf Oil Corp., Gulf Bldg., Pittsburgh, Pa.
Homestake Mining Co., Lead, S. Dak.
Mallinckrodt Chemical Works, Jersey City, N.J.
Mathieson Chemical Corp., Mathieson Bldg., Baltimore, Md.
The Mercoid Corp., 200 Wagaraw Rd., Hawthorne, N.J.
Minneapolis-Honeywell Regulator Co., Micro Switch Div., Freeport, Ill.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div., Purchasing Dept., 4331 Wayne Ave., Philadelphia, Pa.
Monsanto Chemical Co., 918 16th St., N.W., Washington, D.C.
Pennsylvania Salt Mfg. Co., 1000 Widener Bldg., Philadelphia, Pa.
Public Service Electric & Gas Co., 80 Park Place, Newark, N.J.
Quicksilver Products, Inc., 407 Sansome St., San Francisco, Calif.
Standard Oil Co. of Indiana, 910 S. Michigan Ave., Chicago, Ill.
Taylor Instrument Companies, P.O. Box 110, Rochester, N.Y.
Westinghouse Electric Corp., 306 4th Ave., Pittsburgh, Pa.
Wyandotte Chemical Corp., Wyandotte, Mich.

LARGE DEALERS

Associated Metals & Minerals Corp., 75 West St., New York, N.Y.
Ayrton Metal & Ore Corp., 30 Rockefeller Plaza, New York, N.Y.
Bache & Co., 36 Wall St., New York, N.Y.
Barada & Page, Inc., Guinotte Ave. & Michigan Ave., Kansas City, Mo.
Barth Metals Co., Inc., 99-129 Chapel St., Newark, N.J.
F.W. Berk & Co., Inc., Park Place East, Wood Ridge, N.J.
Braun Corp., 1363 S. Bonnie Beach Place, Los Angeles, Calif.
Chemical Mfg. Co., Inc., of Calif., 714 W. Olympic Blvd., Los Angeles, Calif.
Derby & Company, Inc., 10 Cedar St., New York, N.Y.
Stanley Doggett, Inc., 99 Hudson St., New York, N.Y.
Fleischman Burd & Co., 22 W. 48th St., New York, N.Y.
Geotrade Industrial Corp., 141 E. 44th St., New York, N.Y.
Goldsmith Bros., Smelting & Refining Co., 1300 W. 59th St., Chicago, Ill.
Gordon I. Gould & Co., 58 Sutter St., San Francisco, Calif.
W.R. Grace & Co., P.O. Box 286, Church St. Annex, New York, N.Y.
Haesler Metal & Ore Corp., 11 W. 42d St., New York, N.Y.
Chas. P. Hull Co., Inc., 50 Church St., New York, N.Y.
Interchange Commercial Corp., 46 W. 55th St., New York, N.Y.
International Bartering Co., 52 Broadway, New York, N.Y.
International Minerals & Metals Corp., 11 Broadway, New York, N.Y.
International Selling Corp., 122 E. 42d St., New York, N.Y.
L.H. Keller Co., 50 E. 42d St., New York, N.Y.
Leghorn Trading Co., Inc., 141 E. 44th St., New York, N.Y.
Lentex Metal & Chemical Co., 500 Fifth Ave., New York, N.Y.

(continued)

APPENDIX

TABLE 9 (Continued)

DIRECTORY OF SELECTED PRODUCERS, CONSUMERS, AND DEALERS OF MERCURY[136]

LARGE DEALERS

Fred H. Lenway & Co., Inc. 112 Market St., San Francisco, Calif.
Mefford Chemical Co., Sub. McKesson & Robbins, Inc., 5353 Jillson St., Los Angeles, Calif.
Mercantile Metal & Ore Corp., 595 Madison Ave. New York, N.Y.
Mercer Chemical Corp., 11 Mercer St., New York, N.Y.
Merchants Chemical Co., Inc., 60 E. 42d St., New York, N.Y.
Metal Traders, Inc., 26 Broadway, New York, N.Y.
Metallurg, Inc., 99 Park Ave. New York, N.Y.
Metalsalts Corp., 200 Wagaraw Rd., Hawthorne, N.J.
Pacific Vegetable Oil Co., 62 Townsend St., San Francisco, Calif.
Philipp Bros., Inc., 70 Pine St., New York, N.Y.
C. L. Pratt, Jr., 10210 Second Blvd., Detroit, Mich.
Quicksilver Products, Inc., 407 Sansome St., San Francisco, Calif.
Frank Samuel & Co., 2200 Lincoln-Liberty Bldg., Philadelphia, Pa.
The Schmitz-Schoenewaldt-Turner Co., 20 Vesey St., New York, N.Y.
Seaforth Mineral & Ore Co., 3537 Lee Rd., Cleveland, Ohio
William M. Stieh & Co., Inc., 721 River Rd., Teaneck, N.J.
Swiss Bank Corp., N.Y. Agency, 15 Nassau St., New York, N.Y.

APPENDIX

TABLE 10

LIST OF SOME COMPANIES PRODUCING MERCURY CHEMICALS (1968)

Allied Chemical Corp. Industrial Chemicals Div.	Marcus Hook, Pa.
J. T. Baker Chemical Co.	Phillipsburg, N.J.
City Chemical Corp.	Jersey City, N.J.
W. A. Cleary Corp.	New Brunswick, N.J.
Kewanee Oil Co. Harshaw Chemical Co. Div.	Cleveland, Ohio
H. Kohnstamm and Co., Inc. General Color Co. Div.	Newark, N.J.
Mallinckrodt Chemical Works Industrial Chemical Div.	Jersey City, N.J.
Merck & Co., Inc. Metalsalts	Hawthorne, N.J.
Precision Chemical Corp.	Richmond, Calif.
R.S.A. Corp.	Ardsley, N.Y.
Tenneco Chemicals, Inc. Nuodex Div.	Elizabeth, N.J.
Troy Chemical Corp.	Newark, N.J.
Velsicol Chemical Corp.	Wood Ridge, N.J.

APPENDIX

TABLE 11

MERCURY-CONTAINING PESTICIDES[185]

Product	Compound	Producer
Acme Panogen	Methyl mercury dicyandiamide	Acme
Advacide PMA	Phenylmercuric acetate	Advance Division
Advacide PMO	Phenylmercuric oleate	Advance Division
Advacide 60	Phenylmercuric oleate	Advance Division
Agrosol	Methyl mercury dicyandiamide	Chipman
Agrox C	Ethyl mercury chloride and phenylmercuric acetate	Chipman
Agrox	Phenyl mercury urea	Chipman
Calo-clor	Mercuric chloride, mercurous chloride	Mallinckrodt
Calo-gran	Mercuric chloride, mercurous chloride	Mallinckrodt
Calocure	Mercury	Mallinckrodt
Calogreen	Mercurous chloride	Mallinckrodt
Centerchem	Mercuric chloride	Center Chemical, Incorporated
Ceresan L	Methyl mercuric acetate	Du Pont
Ceresan M	Methyl mercury 2,3-dihydroxy propyl-mercaptide	Du Pont
Ceresan M-DB	Ethylmercuric p-toluene sulfonanilide	Du Pont
"Ceresan" Red	Ethylmercuric p-toluene sulfonanilide	Du Pont
Chipcote 25	Ethylmercuric chloride	Du Pont
	Methyl mercury nitrile	Chipman

(continued)

APPENDIX

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
Chipcote 75	Methyl mercury nitrile	Chipman
Coromerc C	Phenyl mercury	Davison
Coromerc Liquid	Phenyl mercury	Davison
Doggett Fison Dap Cal	Mercuric chloride, mercurous chloride	Doggett Fiser
Doggett Fison Dap Cal	Phenylmercuric acetate	Doggett Fiser
Doggett Fison Turf Tox MC	Mercuric chloride, mercurous chloride	Doggett Fiser
Emmi	N-Ethylmercuri-1,2,3,6,-tetrahydro-3,6-endo-methanol-3,4,5-677 Hexachlorphthalimide	Velsicol
E-Z Flo Puratized	Phenylmercuric monoethanolammonium lactate	E. Z. Flo
Fung Chex	Murcuric chloride, mercurous chloride	Wood Ridge
Gallotox	Phenylmercuric acetate	Guard
Gallotox 51	Volatile mercury compounds	Guard
Green Cross Erad	Phenylmercuric acetate	Green Cross
Green Cross Liquid Merlane	Methyl mercury-8-hydroxyquinolinate	Green Cross
Green Cross Liquid San	Methylmercuric acetate Methyl mercury 2,3-dihydroxy propyl-mercaptide	Green Cross
Green Cross Merlane Dust	Methyl mercury pentachlorophenolate	Green Cross
Green Cross San Dust	Methyl mercury pentachlorophenolate	Green Cross

(continued)

APPENDIX

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
GSCI	Mercurous chloride	Gallard-Schlesinger
GSCI	Mercuric chloride	Gallard-Schlesinger
Kroma-Clor	Mercury dimethyl dithiocarbamate	Mallinckrodt
Liquiphene Apple Scab Fungicide	Phenylmercuric acetate	Vineland
Liquiphene Turf Fungicide	Phenylmercuric acetate	Vineland
Mema	Methoxyethyl mercury acetate	Chipman
Memmi	N-methylmercuri-1,2,3,6-tetrahydro 3,6-endomethano-3,4,5,6,7,7-hexachlorophthalimide	Velsicol
Merbam	Phenylmercuric dimethyldithiocarbamate	Chipman
Mercuram	Phenylmercuric dimethyldithiocarbamate	Vineland
Mergamma	Phenyl mercury urea	Chipman
Mergamma C	Ethylmercuric chloride and phenylmercuric acetate	Chipman
Mergamma Liquid	Methyl mercury dicyandiamide	Chipman
Mersolite 88	Phenylmercuric acetate	Wood Ridge
Mersolite 88 W	Phenylmercuric acetate	Wood Ridge
Mersolite 810	Phenylmercuric acetate	Wood Ridge
Mersolite 830	Phenylmercuric acetate	Wood Ridge

(continued)

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
Metasol 10	Phenylmercuric acetate	Metal Salts
Metasol Bi-Cal	Mercuric chloride, mercurous chloride	Metal Salts
Metasol EMCL	Ethylmercuric chloride	Metal Salts
Metasol MMH Concentrate	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH Dual purpose	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH Liquid-dual purpose	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH Liquid seed treatment	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH mercury drill box formulation	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH powder	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol MMH regular	Methyl mercury-8-hydroxy quinolinate	Metal Salts
Metasol Thiram Mercury	Mercuric chloride and mercurous chloride	Metal Salts
Miller (Puratized) Apple Spray	Phenylmercuri monoethanolammonium acetate	Miller Chemical & Fertilizer
Millers Puraspra	Phenylmercuric triethanolammonium lactate	Miller Products
Morsodren	Methylmercury dicyandiamide	Morton
N5 DS	Phenylmercuric triethanolammonium lactate	Guard
New York Science Supply	Mercuric chloride	New York Science Supply

(continued)

APPENDIX

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
Niagara Puratized agricultural spray	Phenylmercuric triethanolammonium lactate	Niagara
Nuodex PMA-18	Phenylmercuric acetate	Nuodex
Nuodex PMO-10	Phenylmercuric oleate	Nuodex
Ortho-LM Apple Spray	Methylmercury-8-hydroxyquinolinate	Chevron
Ortho-LM Seed Protectant	Methylmercury-8-hydroxyquinolinate	Chevron
Panogen 15	Methylmercury dicyandiamide	Morton
Panogen 42	Methylmercury dicyandiamide	Morton
Panterra	Methylmercury dicyandiamide	Morton
Parson's Ready Mix seed treatment	Chloromethoxypropyl mercuric acetate	Parsons
Parson's Slurry Concentrate	Chloromethoxypropyl mercuric acetate	Parsons
Pearson's Merc-O-Dust	Mercurypentanedion	Pearsons
Phelam	Phenylmercuric dimethyldithiocarbamate	Wood Ridge
Phenmad	Phenylmercuric acetate	Mallinckrodt
Phenyl mercury fungicide	Phenylmercuric acetate	Agway
PM 2,4-D	Phenylmercuric acetate	Cleary
PM ACETATE	Phenylmercuric acetate	Guard
PMAS	Phenylmercuric acetate	Cleary
PMB	Phenylmercuric borate	Guard
Proturf fertilizer and fungicide	Phenylmercuric acetate	Scott
Proturf fungicide	Phenylmercuric acetate	Scott

(continued)

APPENDIX

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
Purasan PMA	Phenylmercuric acetate	Guard
Puraseed	Mercury compound	Guard
Puratized Apple Spray	Phenylmercuric monoethanol Ammonium acetate	Metasol Canada, Limited
Puratol	Phenyl mercury	Guard
Puraturf No. 10	Phenylmercuric acetate	Metasol Canada, Limited
Puraturf 10	Phenylmercuric monoethanolammonium lactate	Guard
Quicksan	Phenylmercuric acetate	Stecker
Quicksan 20	Phenylmercuric acetate	Stecker
Quicksan C20	Chloromethoxypropylmercuric acetate	Stecker
Quicksan CMA	Chloromethoxypropylmercuric acetate	Stecker
Real-Kill Moth Proofer	Phenylmercuric lactate	Cook Chemical Company
Samin Corp.	Ethylmercuric chloride	Samin Corporation
Samin Corp. Mercuric Chloride	Mercuric chloride	Samin Corporation
Samin Corp. Mercury Oxide	Mercuric oxide	Samin Corporation
Scutl	Phenylmercuric acetate	Scott
Semesan Bel	Hydroxymercurichlorophenol	Du Pont
Semesan Seed Disinfectant	Hydroxymercurichlorophenol	Du Pont
Semesan Turf Fungicide	Hydroxymercurichlorophenol	Du Pont
Setrete	Phenylmercuric ammonium acetate	Cleary

(continued)

APPENDIX

TABLE 11 (Continued)

MERCURY-CONTAINING PESTICIDES

Product	Compound	Producer
Setrete-Fortified	Ethylmercuric acetate and phenylmercuric acetate	Cleary
Setrete Mist	Ethylmercuric acetate and phenylmercuric acetate	Cleary
Shepard Chemical EMA	Ethylmercuric acetate	Shepard
Shepard Chemical EMC	Ethylmercuric chloride	Shepard
Shepard Chemical EMP	Ethylmercuric phosphate	Shepard
Stauffer Mer-CAD	Phenylmercuric formamide	Stauffer
Stauffer Mer-Sol 7	Phenylmercuric ammonium acetate	Stauffer
Stauffer Mer-Sol 48	Phenylmercuric acetate and ethylmercuric acetate	Stauffer
Stauffer Mer-Sol 51	Phenylmercuric acetate and ethylmercuric acetate	Stauffer
Tersan OM	Hydroxymercurichlorophenol	Du Pont
Troysan CMP Acetate	Chloromethoxypropylmercuric acetate	Troy
Troysan PMA	Phenylmercuric acetate	Troy
Troysan PMB	Phenylmercuric borate	Troy
Troysan PMO	Phenylmercuric oleate	Troy
Ultraclor	Mercuric dimethyldithiocarbamate	Mallinckrodt
Wood Ridge Calomel	Mercurous chloride	Wood Ridge
Wood Ridge Corrosive Sublimate	Mercuric chloride	Wood Ridge
Wood Ridge Mixture 21	Mercuric chloride and mercurous chloride	Wood Ridge